Winter Term – Final Report

MECH 4020

Project:
Human Powered Water Purification System

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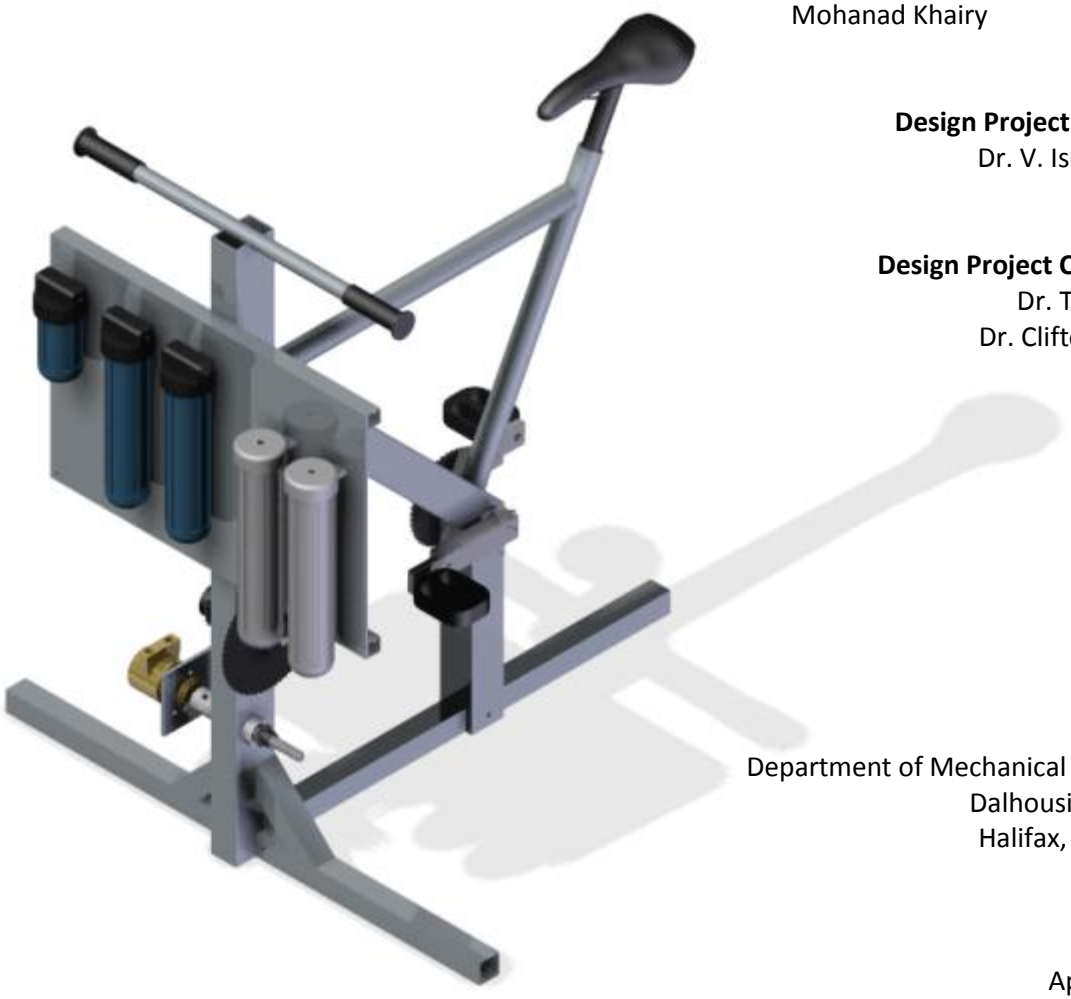

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Executive Summary

The Human Powered Water Purification System is a mechanical device designed to purify water for human consumption using human pedal power. The influent water quality that the system is designed to treat to potable levels may contain Coliform bacteria, E. Coli, total dissolved solids, and organic compounds.

The design utilizes pedal power to drive the membrane purification process. The primary component of the purification system is the reverse osmosis membrane that achieves a level of purification as fine as 0.001 microns.

The Human Powered Water Purification System has been proven to accomplish the initial design requirements set by Team 15. The system is capable of being powered using human pedal power, can produce 9.6 L of potable water after 20 minutes of operation, can remove all existing levels of coliform bacteria and E. Coli from water, can remove ~94% of dissolved solids, weighs ~30 kg and comes out to enclose a volume of 1 m^3. The cost to construct the final prototype was $1110.

1. Introduction

The Human Powered Water Purification System is designed to address the difficulty of accessing clean, safe water in isolated regions such as off-grid residences, camp grounds, summer cottages, etc. In many cases, these remote residences have limited access to electricity and/or fuel. The Human Powered Water Purification System is designed to reduce pathogenic contaminants as well as dissolved salts from source water through the use of a reverse osmosis membrane process. It is designed to produce 10 litres of drinking water after 20 minutes of operation (0.5 Lpm). The system is designed to treat brackish water with microbiological contamination.

The purpose of this document is to provide an overview of the design work completed throughout the course of the project. This report contains information regarding:

1. Design requirements
2. Design selection process
3. Final design
4. Testing Procedures and Results
5. Budget
6. Economic and Environmental Considerations
7. Current project status
8. Design calculations
9. Specification sheets
10. Testing: Raw Data
11. Meeting minutes
12. Engineering drawings

2. Design requirements

The design requirements of this project were divided into the following categories: power requirements, capacity requirements, water quality requirements, physical requirements and cost requirements. In some of these categories, essential requirements were supplemented with optional requirements. The design requirements are summarized in Table 1 below:

Table 1 Summary of design requirements

Category	Essential Requirements	Optional Requirements
Power	▪ Must be human powered ▪ Must be purely mechanical	▪ Can be powered by only one person
Capacity	▪ Must produce a minimum of 0.5 L of potable water per minute of operation	
Water Quality	▪ Must produce clean, safe drinking water from sources potentially contaminated with bacteria, viruses and sedimentation	▪ Can remove dissolved salts
Physical	▪ Must be robust and portable ▪ Must be easy to operate and maintain ▪ Must not exceed 40 kg in mass ▪ Must not exceed 1 m^3 in total volume	
Cost	▪ Prototype materials and construction must not exceed $1200[1]	▪ Projected product fabrication cost in quantity should not exceed $200

[1]Cost requirement revised in January 2013

3. Design Selection Process

The team conducted a thorough literature search in the early fall to identify technologies for purifying water. Aside from being required to remove both pathogenic contaminants and dissolved salts, the technologies considered were also evaluated based on whether they were able to meet the design requirements initially established. Ultimately, reverse osmosis was selected as the primary component to be integrated in the final design for removing both pathogenic contaminants and dissolved solids.

3.1. Purification Systems Considered

During the initial stages of the project, the main difficulty was defining the specific water quality problem to be solved and the available treatment technologies. It was important that a good understanding of existing water purification methods and systems was established. A comprehensive literature review was conducted to establish a fundamental understanding of water purification methods and techniques. A summary of the information that was collected is in Table 2.

Table 2 Summary of existing water purification systems

Purification System	Advantages	Disadvantages
Slow Sand Filtration	▪ Removes microbial contaminants. Typical coliform removals are in the range of 90 – 99% (Lingireddy, 2002).	▪ Relatively large surface area required to produce sufficient filtration rates. ▪ As flow rate increases the amount of coliform removal decreases. ▪ Not effective for removing dissolved ions from water.
Microfiltration	▪ Used to remove particles 0.05 – 5 microns in diameter (Lingireddy, 2002). ▪ Effective as a pre-filtration stage for Ultrafiltration or Reverse Osmosis.	▪ Not effective for removing dissolved ions or viruses from water.
Ultrafiltration	▪ Used typically for particle removal (removal of bacteria and viruses). ▪ Ultrafiltration membranes typically require a pressure differential of 7 to 105 psi; however, the 'loose' membranes require only 10 to 30 psi (Lingireddy, 2002).	▪ Not effective for removing dissolved ions from water.
Reverse Osmosis (RO) Membranes	▪ Used to remove all contaminants from water, yielding a permeate free from dissolved salts, ions, and particles (bacteria and viruses) (Lingireddy, 2002).	▪ Requires a high operating pressure (pressures ranging from 150 to 1500 psi depending on system performance and dissolved salt concentration) (Lingireddy, 2002).
Vacuum Boiling	▪ Reduces the boiling point of water in order to distill at lower temperatures.	▪ Energy intensive process. ▪ Not all the contaminants in the water are separated from the vapor.
Ceramic Filtration	▪ Bacteria, protozoa and microbial cysts are removed (Brown, 2011).	▪ Viruses are generally small enough to pass through the filter. ▪ Must be replaced periodically. ▪ Brittle in nature – hairline cracks form in the filter allowing contaminants to pass through (Brown, 2011).
Solar Disinfection	▪ Has been shown to deactivate pathogenic organisms (Wikipedia, Web.). ▪ Relatively cheap and uses readily available materials such as type 1 plastic.	▪ Solar disinfection depends on amount of sunlight and time. ▪ Effective for clear water only (turbidity blocks UV rays).

Purification System	Advantages	Disadvantages
Activated Carbon Filtration	▪ Removes chlorine, odours, objectionable tastes, dirt, rust, and sand from influent water (Fiore, 1977).	▪ Buildup of organic material and concentration of bacteria combine to foster growth and shedding of bacteria into the water (Tobin, 1981).
Chemical Treatments (Chlorination)	▪ Satisfactory for treating fresh water with pathogenic contaminants (Agardy, 2009). ▪ Ensures the deactivation of bacteria and viruses. ▪ Provides a residual effect in the treated water which prevents growth of bacteria.	▪ Taste, health risks, and public acceptance of chlorinated water in some small communities challenge the use of this treatment method. ▪ Increases the corrosion of certain metals in the pipe system.

Furthermore, a comparison of the particle sizes that can be removed by different types of media and membrane filtration is shown in Figure 1.

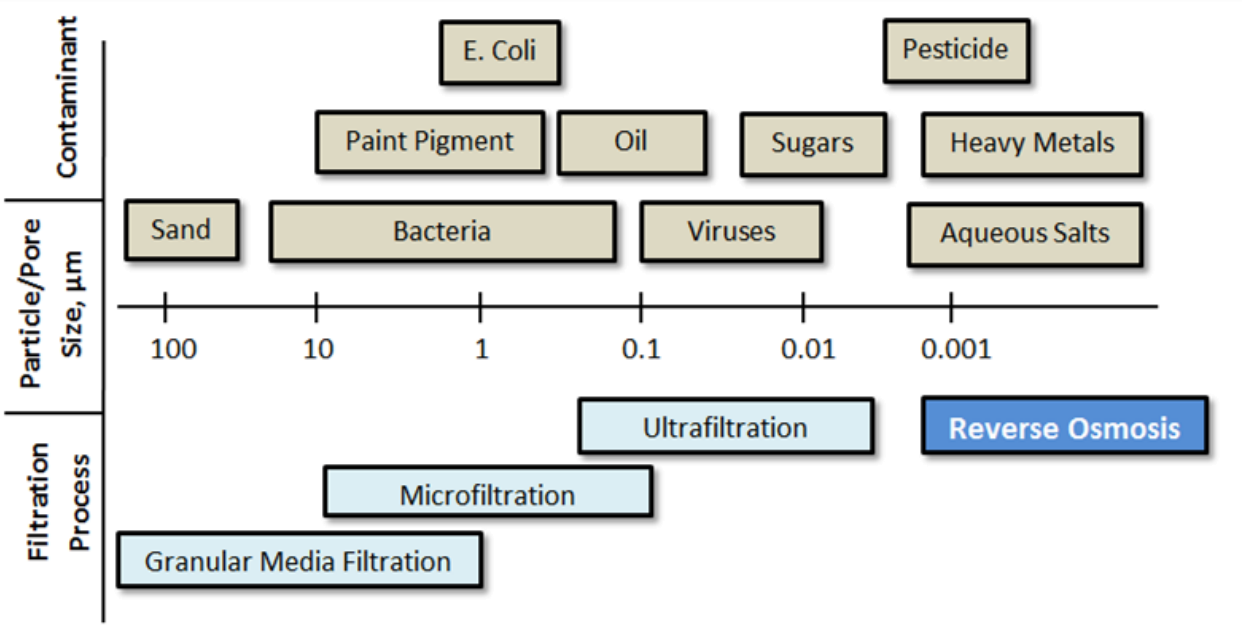

Figure 1 Particle size removal capabilities of different media and membrane filters

3.3. Designs Considered

After researching the different types of water filtration and purification methods currently existing, a set of designs were considered for purifying water of different quality.

3.3.1. Design Considered #1: Slow Sand Filtration with Solar Disinfection

Feed Water Quality:

Low turbidity, fresh water with pathogenic contaminants.

Primary Application:

Rural communities, developing nations, areas with limited access to resources

Description:

This first design that was considered was developed around the concepts of sustainability and simplicity. It is a design that uses slow sand filtration and solar disinfection as the main two components of water purification. The influent contaminated water is poured into an intake container that provides a gravity feed into the system. The contaminated water flows through a perforated plate that disperses the water across the top layer of the sand filter. This provides a uniform distribution of the flow and increases the effective surface area of the slow sand filter. A sketch of the design is shown in Figure 2.

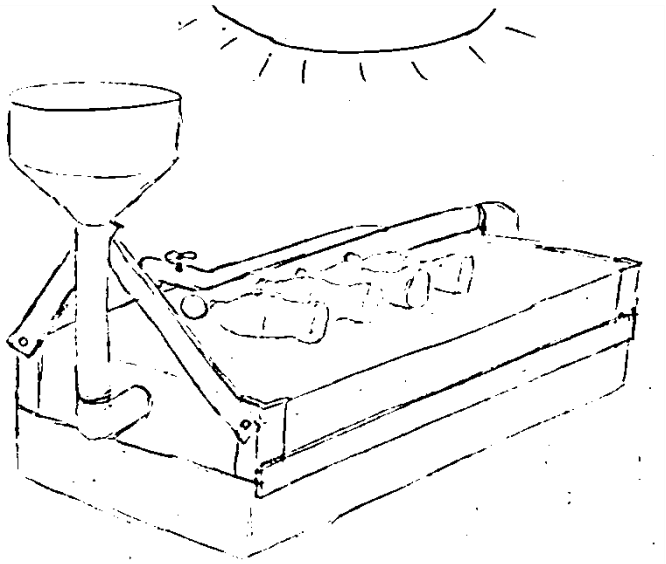

Figure 2 Design considered #1

The contaminated water flows through a layer of large grain sand, a permeable sheet, small grain sand, and finally a gravel bed. The first layer provides filtration of suspended solids in the water. The second layer, the permeable sheet, provides a surface for the microbiologically active sand layer to form. This layer produces a bio-slime that is composed of microorganisms that kill and strain out influent streams containing pathogens. The third layer containing the fine sand removes any smaller sized particles that were not filtered out in the initial stage of the system. The effluent water is then collected in a series of containers made of type 1 plastic that allows sunlight to further disinfect the water.

This design was not selected because it did not fit the design requirement scope of the project. The group felt that this particular deign was too simple and was not challenging enough to meet the requirements of the senior year design project.

3.3.2. Design Considered #2: Ceramic and Reverse Osmosis System

Feed Water Quality:

High turbidity, brackish water with pathogenic contaminants.

Primary Application:

Specifically for remote communities with limited access to modern resources.

Description:

The system utilizes coagulation, ceramic filtration, and a RO membrane to purify the source water. Coagulation would remove sedimentation and decrease the turbidity for the downstream treatment stages. Ceramic filtration is used to remove small particles that could foul the reverse osmosis membrane (such as bacteria). Viruses and ionic compounds are filtered out in the final stage through the RO membrane. The process flow diagram is shown in Figure 3.

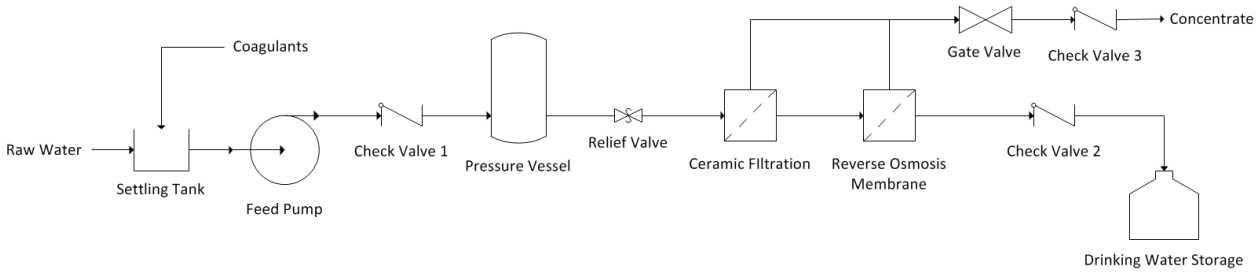

Figure 3 Process flow diagram of design considered #2

This design was not selected because of two main reasons:

1. The coagulation process in the pre-treatment stage of the system was decided to be unnecessary for the chosen scope of the project.
2. Ceramic filters are subject to stress fracture at the high pressures required by the reverse osmosis membrane.

3.3.3. Design Considered #3: Ceramic, Ultrafiltration, and Reverse Osmosis System

Feed Water Quality:

High turbidity, brackish water with pathogenic contaminants.

Primary Application:

Specifically for remote communities with limited access to modern resources.

Description:

This system is identical to the 2nd design that was considered with the addition of an ultrafiltration membrane. This design is composed of a pre-treatment stage, and a 3 stage purification process. The increased number of stages in this particular order is expected to increase the lifetime of the reverse osmosis membrane. The upstream stages of filtration act as pre-filters to remove all contaminants except for dissolved ions. The process flow diagram is shown in Figure 4.

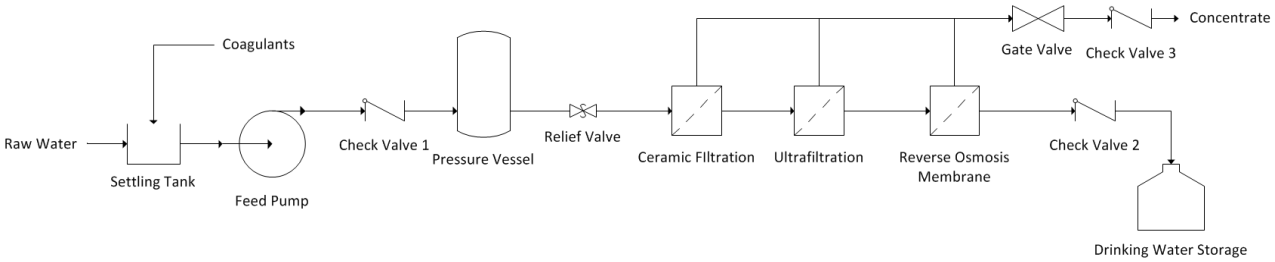

Figure 4 Process flow diagram of design considered #3

This design was not selected because of the added cost associated with the increased number of filters in the process. The benefit of increasing the lifetime of the RO membrane is not expected to outweigh the initial cost of the system (low payback).

3.3.4. Fall Term Selected Design: Microfiltration and Reverse Osmosis System

Feed Water Quality:

Low turbidity, brackish water with pathogenic contaminants.

Primary Application:

Specifically for remote communities with limited access to modern resources.

Description:

The design that was selected at the end of the fall semester consisted of a system that would be able to purify brackish water with micro-bacterial contamination. It consisted of a mechanically driven shaft that powers a positive displacement pump. The system utilized a microfiltration membrane in series with a reverse osmosis membrane. The microfiltration membrane was selected to serve as the filter for pre-treatment in order to mitigate fouling of the RO membrane. It was expected to remove some of the particle and microbial contamination with sizes as small as 0.2 microns. The

reverse osmosis filter achieves filtration of dissolved ions at a rejection rate of ~98% (AMI Membrane Inc., Web.). A process flow diagram is shown in Figure 5.

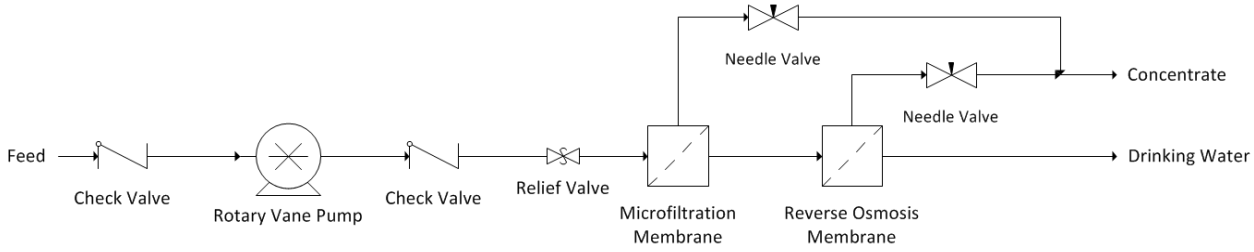

Figure 5 Water purification process flow diagram

This design was initially chosen because of it's ability to remove pathogenic contaminants and dissolved salts, because of it's relative simplicity compared with a three stage membrane process, and because of the suitability of a microfiltration membrane for RO pretreatment (Buckley and Jacangelo, 1996).

3.3.5. The Final Design

Feed Water Quality:

Low turbidity, brackish water with pathogenic contaminants.

Primary Application:

Specifically for remote residences without city water supply and electricity

Description:

In the winter semester the team approached an obstacle with regards to the availability of the specific membranes specified in the fall term design selected (shown in Figure 5). After ordering the materials, the suppliers contacted the university to inform them of additional freight charges of $120. Since costs were required to be cut down anyway at that stage of the project, there was no possibility that the additional charges could be accepted. As a result, the shipping order was cancelled and a search for new suppliers was initiated. No local suppliers could supply the same type of membranes that were initially specified. As a result, the purification system had to be redesigned using components that were available from local distributors that were guaranteed to be available. Two smaller reverse osmosis membranes were selected in addition to a 5 micron sediment filter, an activated carbon filter, and a 0.35 micron Ultra filter to accomplish what was

initially intended by the selected fall semester design. A schematic of the final design that was assembled is displayed in Figure 6 below.

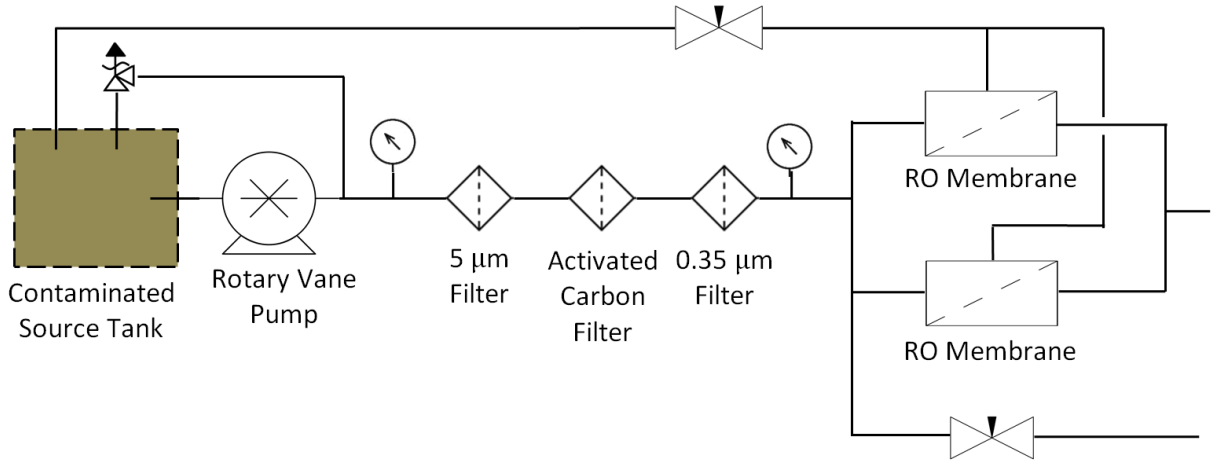

Figure 6 Final design of the hydraulic assembly of the Human Powered Water Purification System

Specific details concerning the final design illustrated in Figure 6 are thoroughly discussed in the proceeding section of this report.

4. Final Design

A CAD rendering of the final design of the human powered water purification system is shown in Figure 7.

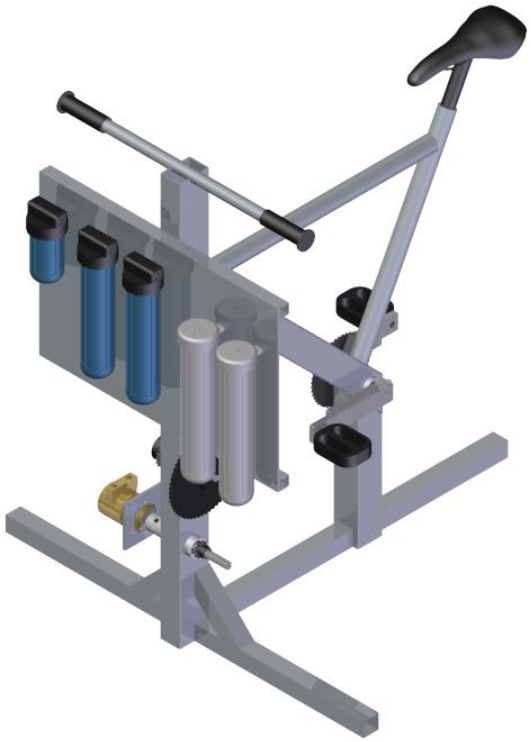

Figure 7 CAD rendering of final design

The following sections will discuss the components of the final design categorized into 3 main categories:

1. The frame
2. The drivetrain
3. The hydraulic circuit

4.1. Frame Design

The frame for this design was designed to be simple and robust. This particular design uses aluminum box tubing because it is easily attainable and easy to weld and machine. Aluminum is more expensive than steel, but has a higher strength to weight ratio, allowing the frame to be made lighter for transportation.

The basic dimensions were determined by researching bicycle geometries for ergonomic pedalling in the sitting position. The seat post angle is designed to be 72° from the vertical. This angle was chosen after researching that typical seat post angles are between 70 and 74 degrees (Hanaki-Martin, 2012). The final dimensions of the frame are 36” x 40.5” x 41.5” (including the hydraulic components). The current design allows the seat to be adjusted approximately one foot to accommodate people of various heights. The structural members of the frame can accommodate up to 250 lbm.

One important consideration for the design of the frame was that the assembly must be compact for easy shipment. To integrate this concept into the design, the frame was designed in three separate welded components that are bolted together by the user. These three components can be taken apart and stacked flat for compactness as displayed in Figure 8.

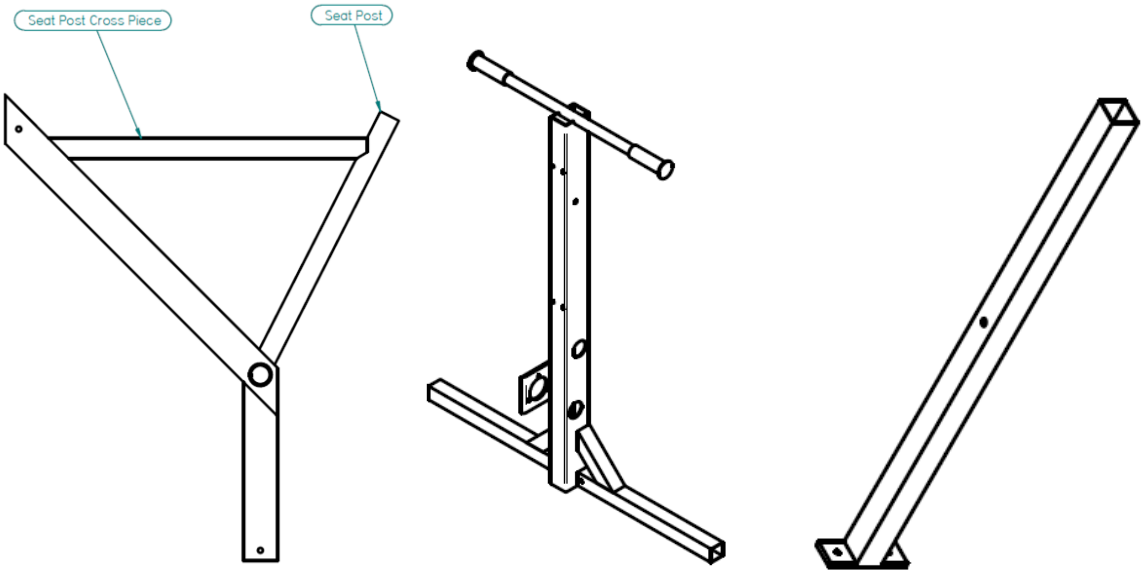

Figure 8 Frame components

4.2. Drivetrain

The final drivetrain design consists of a two stage, 13.5:1 sprocket system used to increase the rotational speed of pedaling to the pump shaft. During the literature search, the team found that a human can produce the most power at around 90 RPM. This is demonstrated in Figure 9 below in which human power output is plotted vs. pedalling speed for one individual.

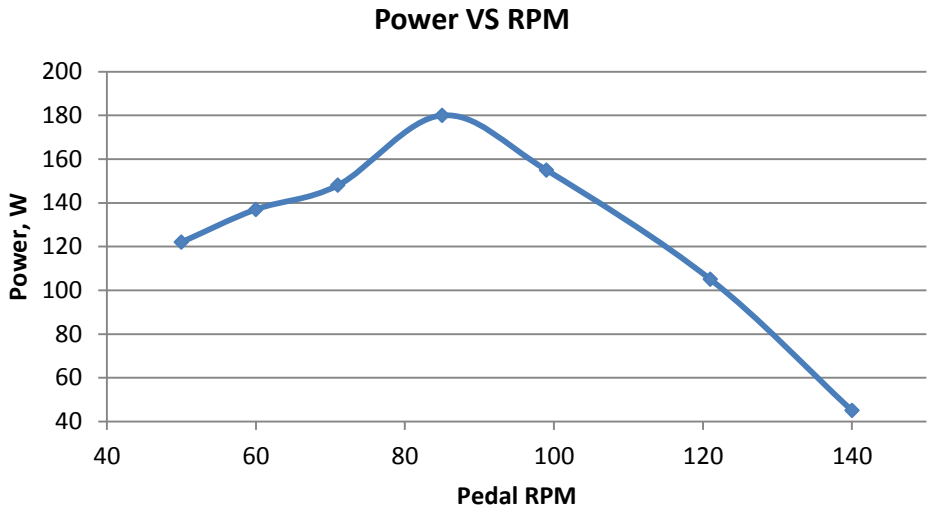

Figure 9 Pedaling power vs. RPM (Wilson, 2004).

The sprocket gearing was chosen to increase the pedaling speed to approximately 1200 RPM (The choice of 1200 RPM will be discussed in the pump selection section). In the first stage, a 45 tooth sprocket at the pedal crank is coupled to a 20 tooth sprocket at an intermediate shaft. A 60 tooth sprocket on the intermediate shaft is coupled to a 10 tooth sprocket on the pump shaft. The drivetrain is detailed in Figure 10.

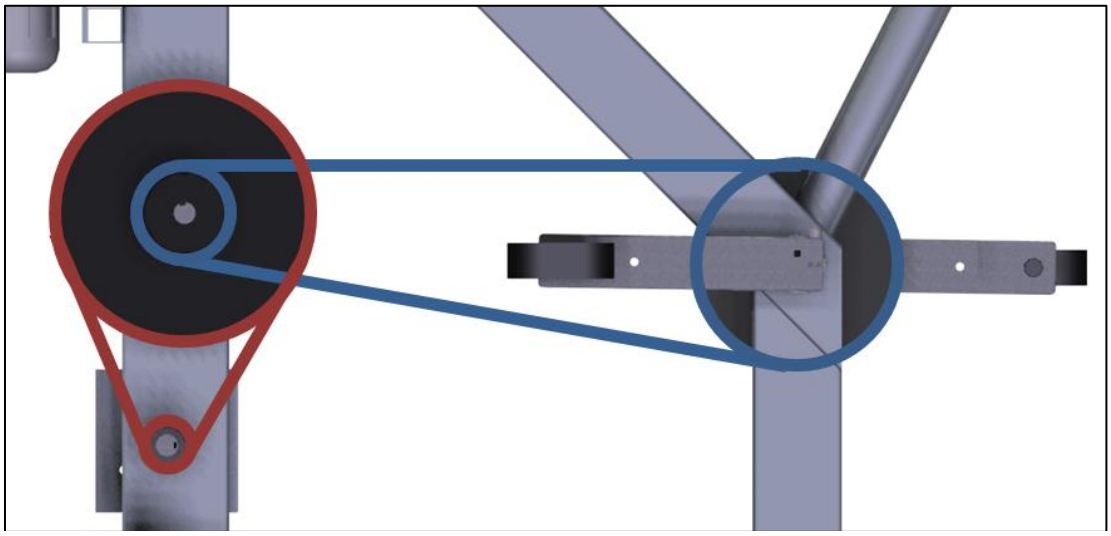

Figure 10 13.5:1 Sprocket Drivetrain

The individual components of the drivetrain are shown in Figure 11.

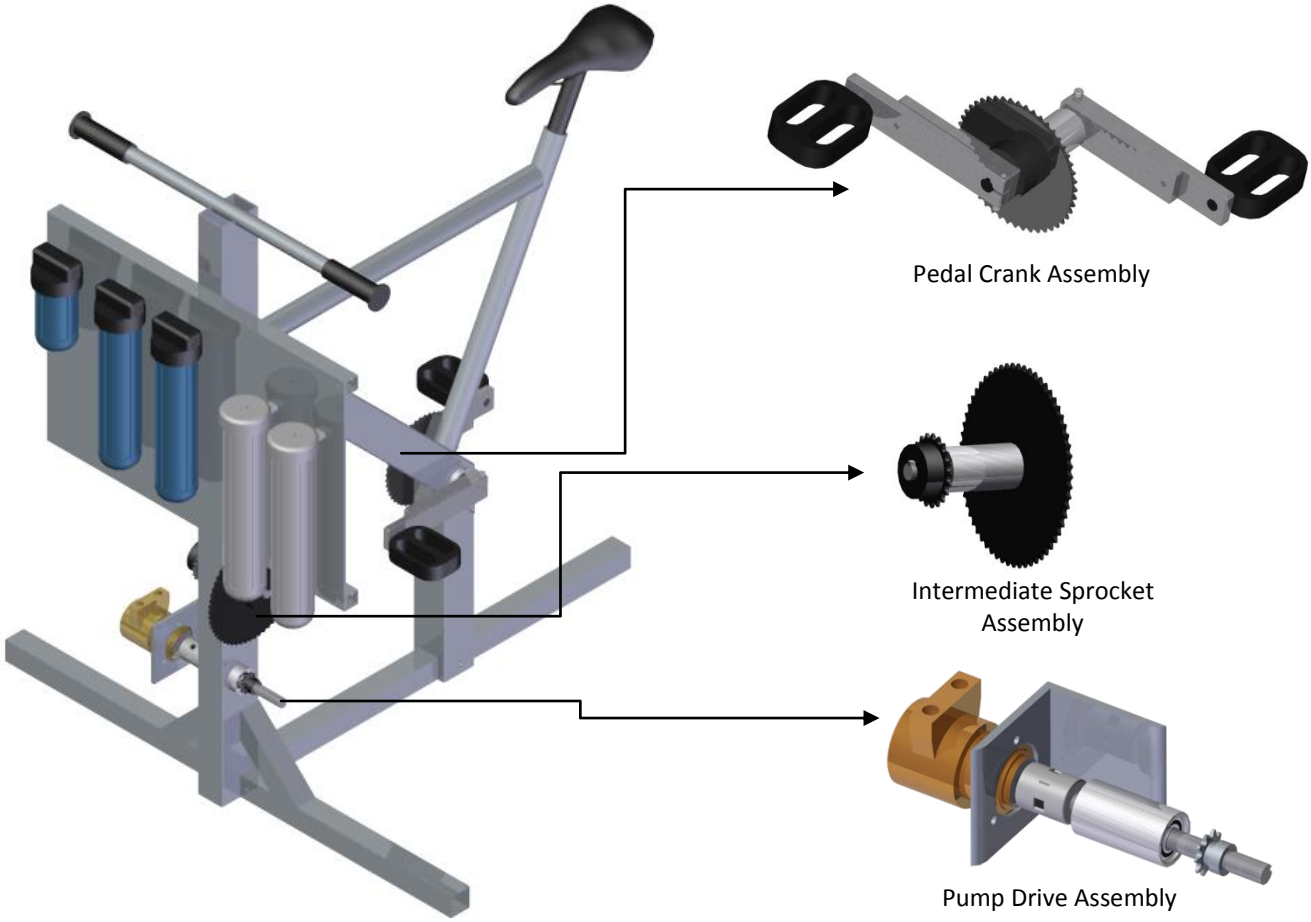

Figure 11 Mechanical drivetrain components

4.2.1. Pedal Crank Assembly

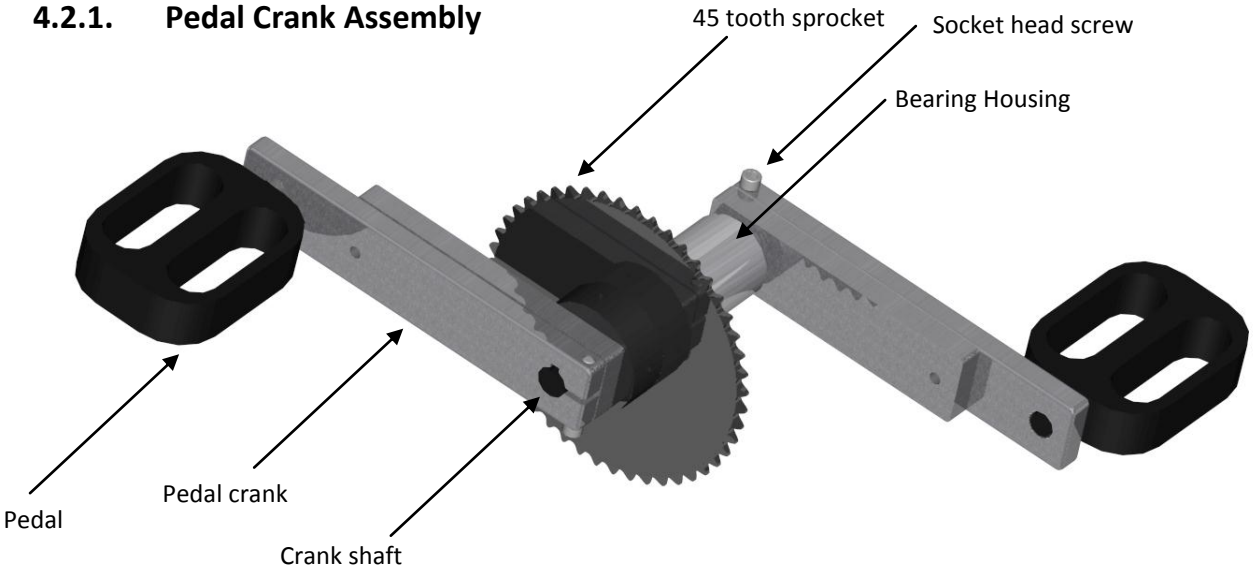

Figure 12 Pedal crank assembly

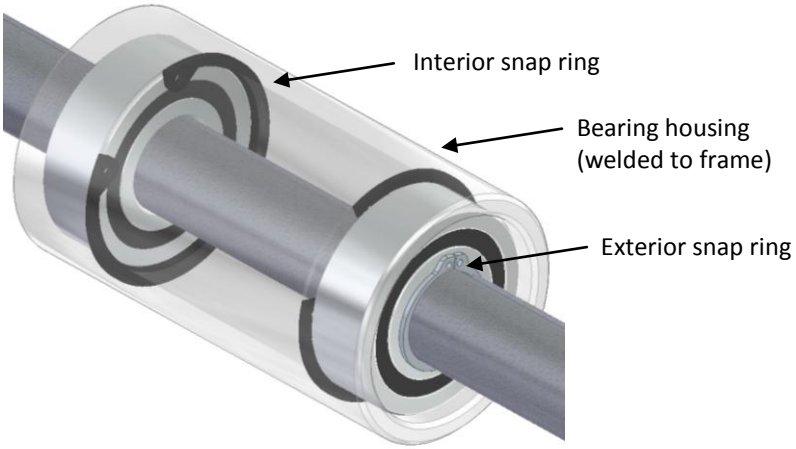

Figure 13 Bearing housing

The pedal crank assembly (displayed in Figure 12) is the power transducer between the driver and the pump. It is designed for simple fabrication and assembly using standard sized materials. A bearing/shaft housing fabricated from a length of aluminum pipe is welded to the frame. Ball bearings are held in place in the pipe using snap rings as seen in Figure 13. The exterior snap rings constrain the shaft while the interior snap rings constrain the bearings within the bearing housing. The reason the bearing housing was designed in this manner was mainly because of ease of manufacturing.

The team considered purchasing a pre-fabricated bicycle bearing hub and sprocket; however, the chosen design was selected based on ease of interfacing with the bicycle frame and cost of components. Considering production in quantity, this design is expected to be more cost effective than purchasing custom bicycle components. Also, should the team find it necessary to test different gear ratios, the sprocket can easily be removed and inter-changed. Stress calculations were performed on the shaft, key, crank, and bearings to ensure that they were capable of operating within the allowable limits of the mechanical system. The calculations for the components were based on an applied torque corresponding to 150 Watts of power and 90 rpm pedal speed. The calculations are in Appendix B. A summary of the main mechanical components in the pedal crank assembly with their selected sizes is in Table 3.

Table 3 Summary of components in pedal crank assembly

Component	Quantity	Size
Steel shaft	1	5/8” dia.
Pedal crank	2	8”x0.5”x1.5”
45 tooth sprocket	1	Sprocket for #35 Chain, 3/8" Pitch, 45 Teeth, 5/8" Bore
Bearing Housing	1	1 ¼” SCH 80
Interior Snap Rings	2	1 3/8” bore diameter
Exterior Snap Rings	2	5/8” shaft diameter
Ball Bearings	2	5/8” shaft diameter
Socket Head	2	¼”-20 x 1.5”
Steel Flat bar	2	6” x 0.5” x 1.5”

4.2.2. Intermediate Sprocket Assembly

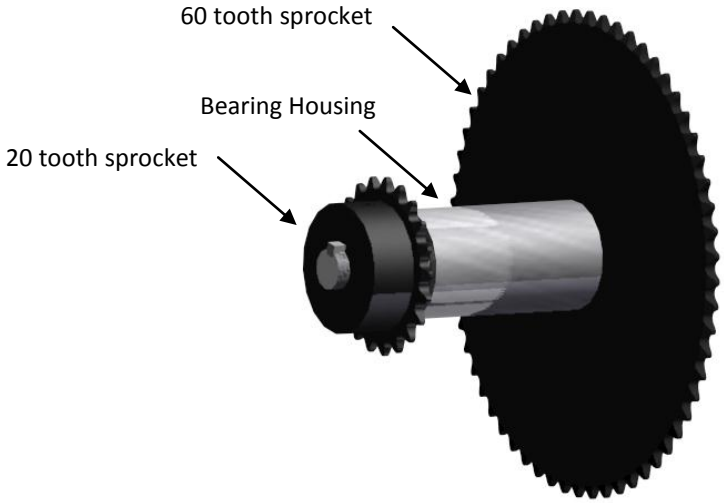

Figure 14 Intermediate sprocket assembly

Based on a maximum recommended single stage reduction of 7:1 (Renold Jeffrey, Web.), two stages were required to produce the 13.5:1 gear ratio. The bearing housing shown in Figure 14 is an identical assembly of parts as the one shown in Figure 13.

A summary of the main mechanical components of the intermediate sprocket assembly with their selected sizes is in Table 4.

Table 4 Summary of components in intermediate sprocket assembly

Component	Quantity	Size
Steel shaft	1	5/8” dia.
60 tooth sprocket	1	Sprocket for #35 Chain, 3/8" Pitch, 60 Teeth, 5/8" Bore
20 tooth sprocket	1	Sprocket for #35 Chain, 3/8" Pitch, 20 Teeth, 5/8" Bore
Bearing Housing	1	1 ¼” SCH 80
Interior Snap Rings	2	1 3/8” bore diameter
Exterior Snap Rings	2	5/8” shaft diameter
Ball Bearings	2	5/8” shaft diameter

4.2.3. Pump Drive Assembly

The pump drive assembly is composed of machine parts that transmit the power from the drive train to power the pump. The chain size was selected to be an ANSI/ISO #35 chain size. This chain size was selected based on the rated load according to one supplier (McMaster-Carr, Web.). A view of the general assembly is shown in Figure 15.

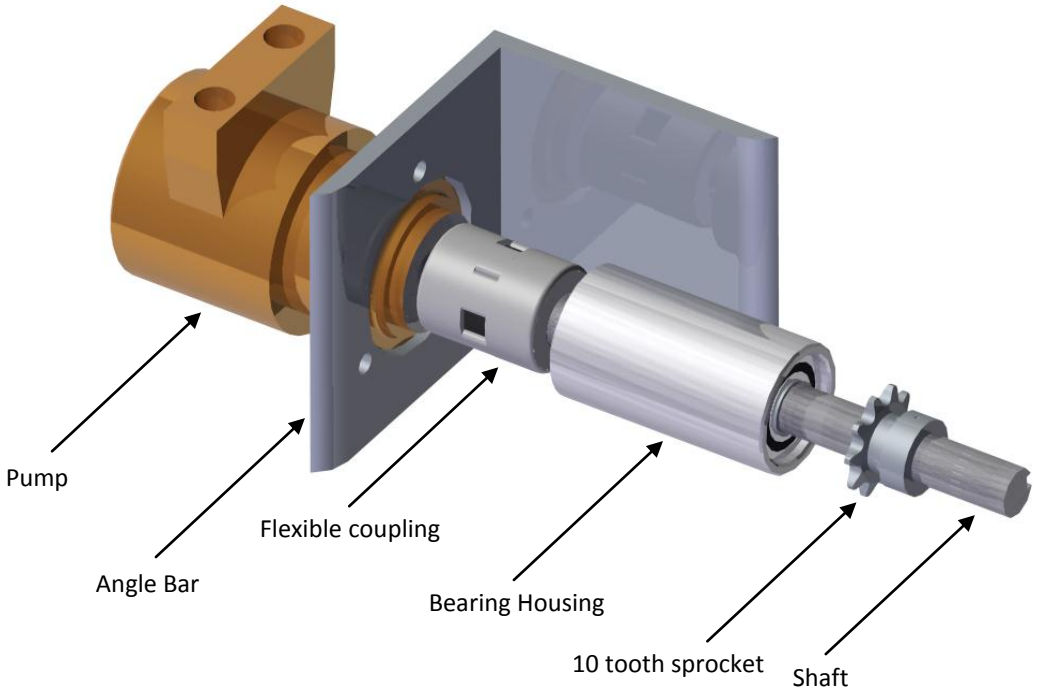

Figure 15 Pump drive assembly

The bearing housing shown in Figure 15 is an identical assembly of parts as the one shown in Figure 13. The steel shaft was originally sized to match the bore size of the bearings, sprocket, and flexible coupling that could all be purchased. Stress calculations were performed on the shaft, shaft key, and bearings to ensure that the stresses induced in the system were well below the allowable limits of these components. Supporting calculations may found in Appendix B. A summary of the main mechanical components with their selected sizes is in Table 5.

Table 5 Summary of components in pump drive assembly

Component	Quantity	Size
Steel shaft	1	5/8” dia.
10 tooth sprocket	1	Sprocket for #35 Chain, 3/8" Pitch, 10 Teeth, 5/8" Bore
Bearing Housing	1	1 ¼” SCH 80
Interior Snap Rings	2	1 3/8” bore diameter
Exterior Snap Rings	2	5/8” shaft diameter
Ball Bearings	2	5/8” shaft diameter
Flexible Coupling	1	7/16” and 5/8” coupling hubs
Angle bar	1	4”x4”x¼”
Pump	1	70 gph[1]

[1] Pump specification sheet attached in Appendix D

4.4. Hydraulic Circuit

The physical layout of the hydraulic circuit is shown in Figure 16 below.

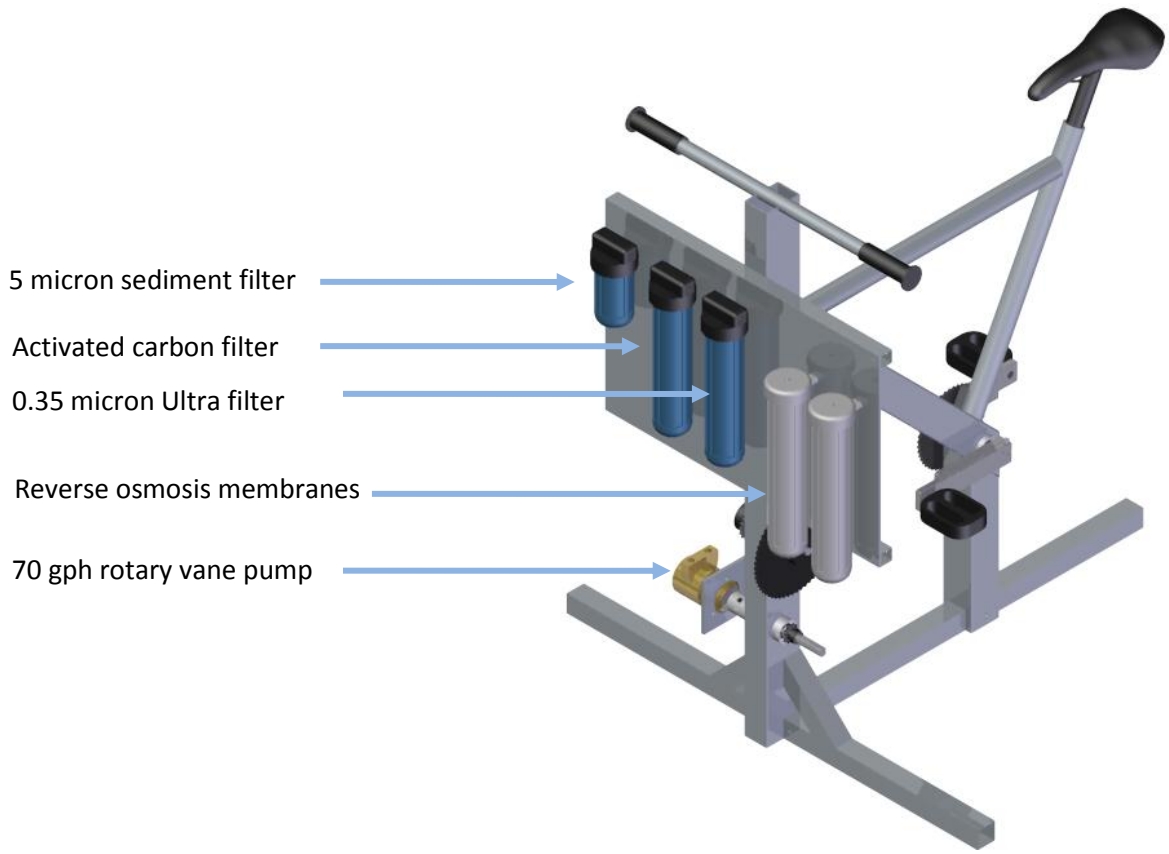

Figure 16 Physical layout of the hydraulic circuit

4.4.1. Pump Selection

A Fluid-o-Tech rotary vane pump designed for water treatment applications was chosen to supply a consistent, well-defined flow rate. The rotary vane pump is a positive displacement pump, meaning that its output flow rate is approximately proportional to its rotational speed. This characteristic made it possible to easily predict and control the output flow rate of the purification system. The pump was sized with considerations for both the required flow rate of the system and the practicality of different sprocket reduction ratios used to drive the pump. The pump was sized to produce flow at 3.3 Lpm in order to meet system requirements. The 3.3 Lpm flow rate requirement is based on the ratio of water penetrating the reverse osmosis membrane to the water that flushes through the membrane and is recirculated (the flow characteristics will be described in greater detail in the following subsections). The system was designed so that this ratio (the recovery rate) would be 15% as specified by the membrane manufacturer. Since 0.5 Lpm of clean water production (permeate) was set in our design requirements, a total flow rate of 3.3 Lpm was needed.

The Fluid-o-Tech pump is manufactured as a replacement for a near identical product manufactured by Procon Pumps. In Procon's literature, the minimum pump rotation speed for the similar pump was specified as 800 RPM. The drivetrain was chosen to drive the pump at about 1200 RPM at normal pedaling speeds in order to stay well above the 800 RPM lower limit without going so fast as to cause increased inefficiency in the drivetrain associated with friction caused by driving the pump shaft at high speeds.

A Fluid-o-Tech rotary vane pump rated at 70 gph (4.4 Lpm) at 1750 RPM was selected in order to provide the required flow rate at the design pump shaft speed of 1200 RPM. The specification sheet for this pump can be found in Appendix D. Since for a rotary vane pump the flow rate is proportional to the speed, the actual output of the pump at design conditions is:

$$(4.4\ \text{Lpm})\frac{1200\ \text{RPM}}{1750\ \text{RPM}} = 3\ \text{Lpm}$$

The 3 Lpm is slightly below the desired 3.3 Lpm. The original design specified an 80 gph pump to provide the desired flow rate, however, the team was unable to procure an 80 gph pump and purchased the next best available pump. In the future, the team could adjust the sprocket system to achieve the specified 3.3 Lpm. For the purposes of this project, the desired permeate flow rate was achieved by adjusting the recovery rate of the system (increasing it above 15%).

4.4.2. Purification System

The final design selected for the purification system is a reverse osmosis membrane filtration process. Contaminated water is pumped from a holding tank, and is conditioned before entering the reverse osmosis membranes using a pre-treatment stage consisting of three cartridge filters. As the water enters the reverse osmosis membranes, system backpressure forces about 15% of the entering water through the membrane. The remaining 85% of the water that enters the reverse osmosis membranes flushes over the surface of the membrane and is circulated back through a control valve to the contaminated holding tank. The recovery rate of the system is defined as the ratio of water that passes through the membranes (the permeate) to the water that enters the membrane. The water flushing over the membrane is the 'concentrate'. Normal operation of the membranes requires that the recovery rate be kept near 15%, because the concentrate stream is required to continuously flush contaminants away from the membrane. The complete purification system is detailed in Figure 17.

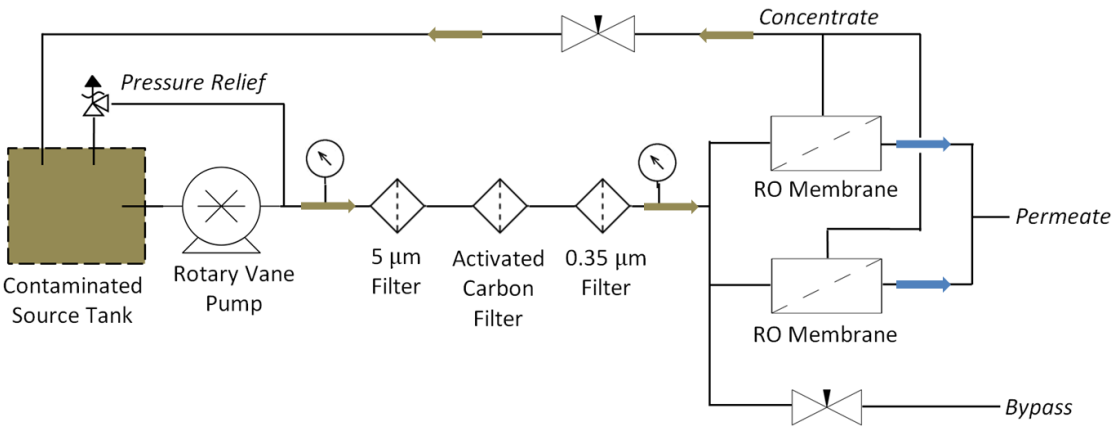

Figure 17 Schematic illustrating the hydraulic circuit

The purification system includes an adjustable pressure relief valve in order to limit the system pressure to a set value. The system components are sized to handle a maximum system pressure of 125 psi. Without the use of a relief valve, a user could produce a large pressure spike by jumping on a pedal and damage the system. The relief valve mitigates this danger.

The bypass line allows a user to produce significantly more flow rate at a lower system pressure if the use of the reverse osmosis membranes is deemed unnecessary. This could be the case, for example, if a user wanted to produce water for bathing or cleaning that did not require rigorous bacteria and dissolved solids removal. The bypass line also enabled the team to sample the water after the pre-treatment stage in order to evaluate its effectiveness.

The following subsections will describe each section of the process in detail, and will outline the selection and sizing of equipment.

4.4.2.1. Pre-treatment Filtration

Because of the fine pore size and material composition of the reverse osmosis membranes, the feed water must be pre-treated in order to remove particles and chemicals that could foul or damage the membranes. The pre-treatment process consists of a 5 µm pore size sediment filter, an activated carbon filter, and a 0.35 µm ultra filter.

The 5 µm filter is used to remove larger particles of sedimentation. It is a standard size cartridge filter, and requires replacing approximately once every six months, or as often as needed depending on the quality of the source water.

The activated carbon filter was a later addition to the design. The activated carbon medium within the filter is derived from coconut shell, anthracite or some other organic material (Dickenson,

1997) and is used to remove chlorine and other chemicals by a combination of catalytic reactions and adsorption to the carbon. The reverse osmosis membranes chosen for this design require that the chlorine content of the feed water be below 0.1 ppm. Since the team had planned to use tap water for most of the system performance testing, the activated carbon filter was required to reduce the chlorine content of the water. In the Halifax Regional Municipality, the chlorine content of the city water is kept between 0.2 and 1.1 ppm (HRWC, Web.). The activated carbon filter has the added benefit of removing colour, tastes and odours caused by organic contaminants (Dickenson, 1997). Like the 5 μm filter, the activated carbon filter must be replaced as often as it becomes clogged.

The 0.35 μm 'ultra-filter' is used as a final treatment before the reverse osmosis to remove even finer particles that could damage the reverse osmosis membranes. During testing, the team found that on occasion the ultra-filter removed E.coli from the source water.

Each of the filters used for pre-treatment are dead-end type filters. Since the system as designed has no backwashing capabilities, all the contaminants that enter the filters will be retained within the filters until the increase in pressure required to force water through the filters becomes so great that replacement is necessary.

Initially, the team had expected that the total pre-treatment stage would have a pressure drop on the order of 5 to 10 psi. However, during testing, the pressure drop was found to be negligible. Using the analogue pressure gauges the team purchased from McMaster-Carr, there was no measurable pressure drop across the pre-treatment stage for the normal range of flow rates seen by the system.

Once the contaminated source water has been conditioned, it can be fed to the reverse osmosis membranes for total bacteria removal and total dissolved solids reduction.

4.4.2.2. Reverse Osmosis Membranes

Osmosis refers to the natural passage of water through a semi-permeable membrane separating two liquids of different salt concentration (Dickenson, 1997). The system wants to find equilibrium where the salt concentration is the same on either side of the membrane. The passage of water from the low concentration to the high through the membrane creates a pressure differential, known as the osmotic pressure. The osmotic pressure differential is often illustrated using a U-tube configuration as shown in the following figure.

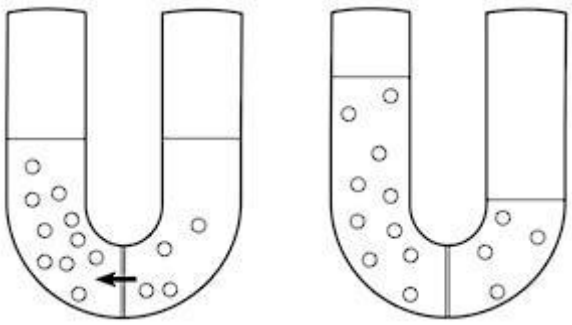

Figure 18 Osmosis (PASCO, Web.)

Reverse osmosis occurs when a pressure is applied to the solution of higher concentration, causing the process to reverse and the water to flow from the higher concentration side of the membrane to the lower. The pressure required to move water through the membrane is a function of the characteristics of the membrane as well as the salt concentration of the water.

Most commercially available reverse osmosis membranes are either spiral wound or hollow fine fibre type. For small scale applications, the team was only able to identify spiral wound membranes. A spiral wound membrane is illustrated in the following figure.

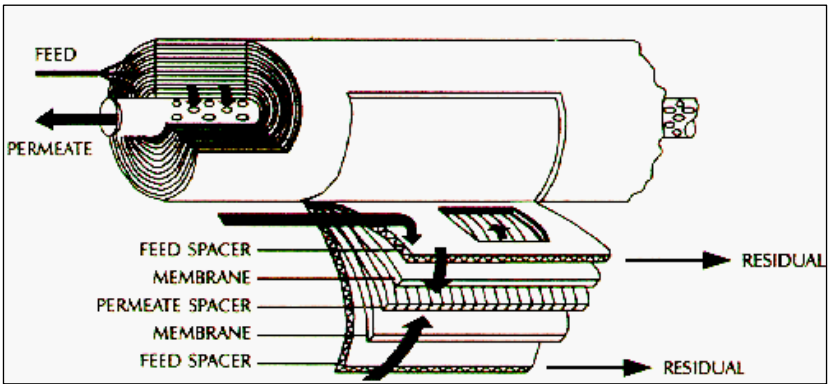

Figure 19 Spiral wound membrane element (RPI, Web.)

The reverse osmosis membranes used in the Human Powered Water Purification System were selected to provide the required flow rate of 0.5 Lpm. A significant portion of the project was spent selecting, sourcing, and evaluating the characteristics of the reverse osmosis membranes.

The pressure drop across an RO membrane is a complex relation between flow rate, recovery rate, salt concentration, and water temperature. Using the rated operating conditions of a membrane given by the manufacturer (AMI, Web.), the pressure drop can be estimated using the following equation (AMI, Web).

$$P_{actual} = \frac{Q_{p,actual} * C_T}{Q_{p,rated}}(P_{rated} - \Delta\Pi_{rated}) + \Delta\Pi_{actual}$$

Where P is the trans-membrane pressure in psi required to produce permeate flow rate Q_p, ΔΠ is the osmotic pressure across the membrane in psi, and C_T is a temperature correction factor. The osmotic pressure is a function of the concentration of salt in the feed water and the permeate water. According to AMI Membranes, a manufacturer of reverse osmosis membranes, the osmotic pressure can be estimated using the following rule of thumb:

$$\Delta\Pi \cong \frac{C_f}{100}$$

Where ΔΠ is the osmotic pressure differential in psi and C_f is the total dissolved solids concentration of the feed water in parts per million (ppm). A more accurate calculation can be performed by taking into account the salt concentration of the product water (Kucera, 2010); however, because of the high salt rejection rate of the membranes (98% salt rejection specified for the Black Max membrane) the effect on osmotic pressure is neglected.

In the fall term, the team presented a comparison of different reverse osmosis membranes in order to choose the best piece of equipment based on the system flow requirements and cost. The comparison resulted in a choice of a 2.5x21" Low Energy Brackish water membrane as the best option. However, in the winter term, the team had difficulty sourcing this membrane. The team ultimately chose to use two Black Max Residential Thin Film Composite reverse osmosis membranes rated for 100 gpd (0.26 Lpm) of permeate flow rate at a system pressure of 65 psi for 500 ppm feed water. The specification sheet for this membrane can be found in Appendix D.

The use of two 1.8x12" Black Max RO membranes in parallel over a single 2.5x21" LE brackish water membrane may be validated by looking at the system flow and cost requirements for each. The results of the calculation are shown in the table below. The calculation assumes that the pump efficiency is 35%, and that the drivetrain efficiency is 85%.

Table 6 Comparison of membrane configurations

Membrane Selection/Configuration	Required Pressure, psi	Required Power, W	Total Cost
2.5x21" LE Brackish *-single element*	75	90	$230
1.8x12" Residential RO *– 2 elements in parallel*	76	92	$180

[1]Total cost includes all required membranes and housings.
[2]Based on 0.5 Lpm of total permeate flow rate for water with 2000 ppm TDS at 25 ℃

As can be seen in the comparison shown in Table 6, the use of two small membranes in parallel is comparable to the use of a single medium sized element in terms of the system pressure and power requirements to produce the desired 0.5 Lpm of permeate. However, the use of two small elements offers a significant cost saving over the use of the single medium sized element.

Use of the Black Max 100 gpd membranes was validated by calculating the flow characteristics over a range of operating conditions. The simulation predicts the permeate flow rate that would be produced for various system backpressures (controlled by the recovery rate valve) and various human power inputs. In Figure 20, two Black Max membranes are simulated in parallel such that the flow through each membrane is assumed to be the same. For the power input calculation, the user is assumed to be pedaling at a constant 90 RPM. The results of the simulation are shown in Figures 20 and 21 below.

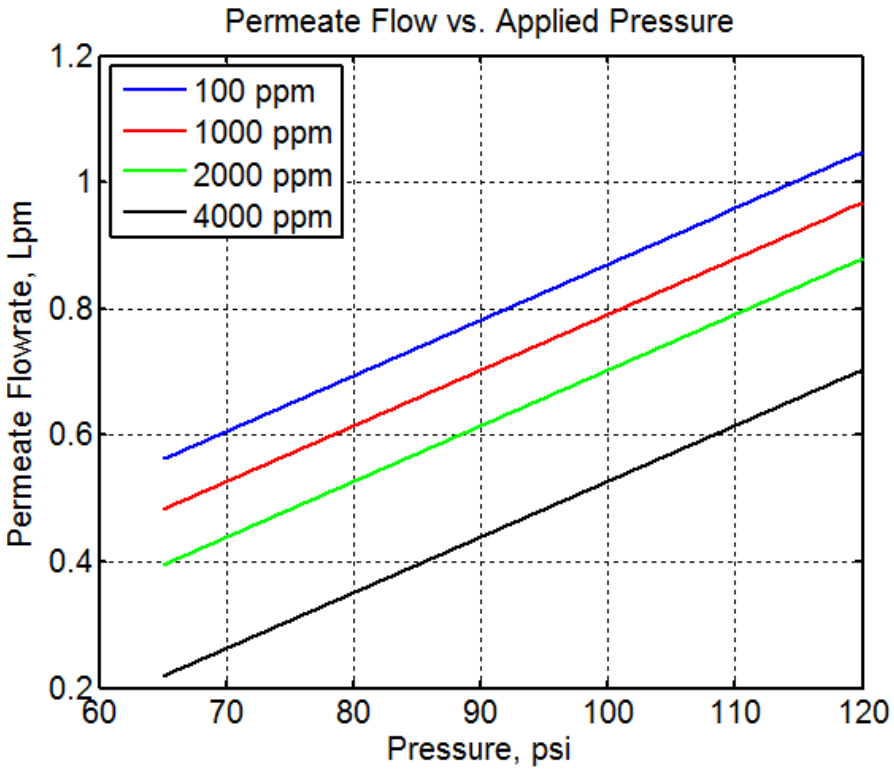

Figure 20 Permeate flow rate vs. applied pressure for two Black Max 100 gpd membranes in parallel.

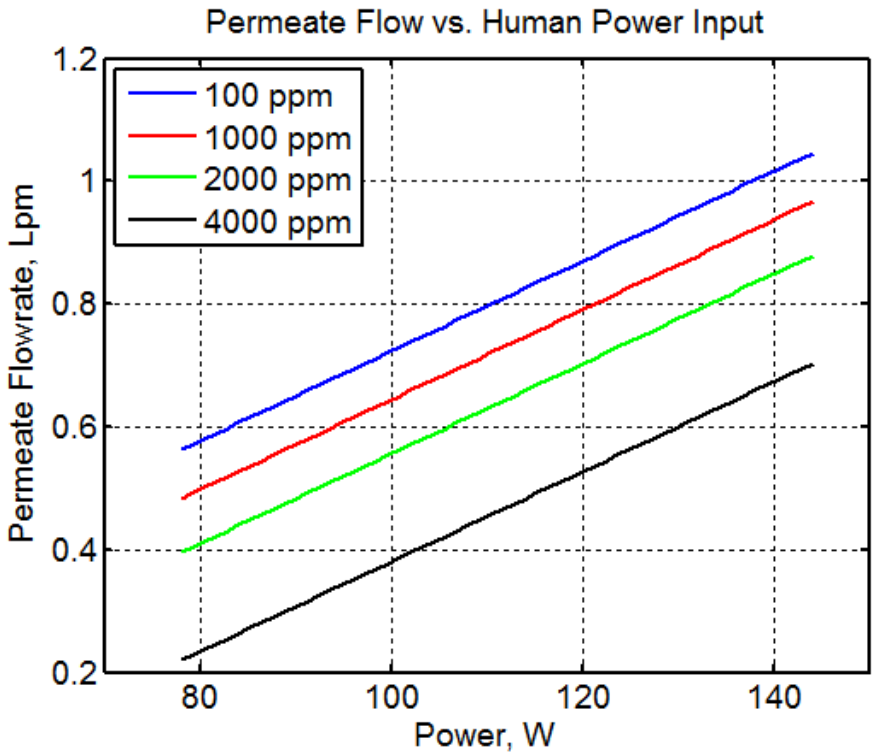

Figure 21 Permeate flow rate vs. human power for two Black Max 100 gpd membranes in parallel.

In order to calculate the human power requirement, the efficiency of the rotary vane pump was taken into account. Although Fluid-o-Tech does not cite pump efficiencies, the team found documentation citing pump brake horsepower for a near identical Procon pump. The efficiency of the pump was found to be in the range of 35%. Also, the efficiency of the sprocket drivetrain was assumed to be 85%.

Note in the graphs that as the salt concentration of the feed water increases, the pressure and power requirements also increase. Based on the simulation, the membranes are expected to produce the 0.5 Lpm of flow desired to meet the design requirements. The 0.5 Lpm is also achievable within human power capabilities. In order to understand how much power a human can produce, the team examined a study on the maximum power a healthy adult can produce over a period of time. The results of the study are summarized in the following figure.

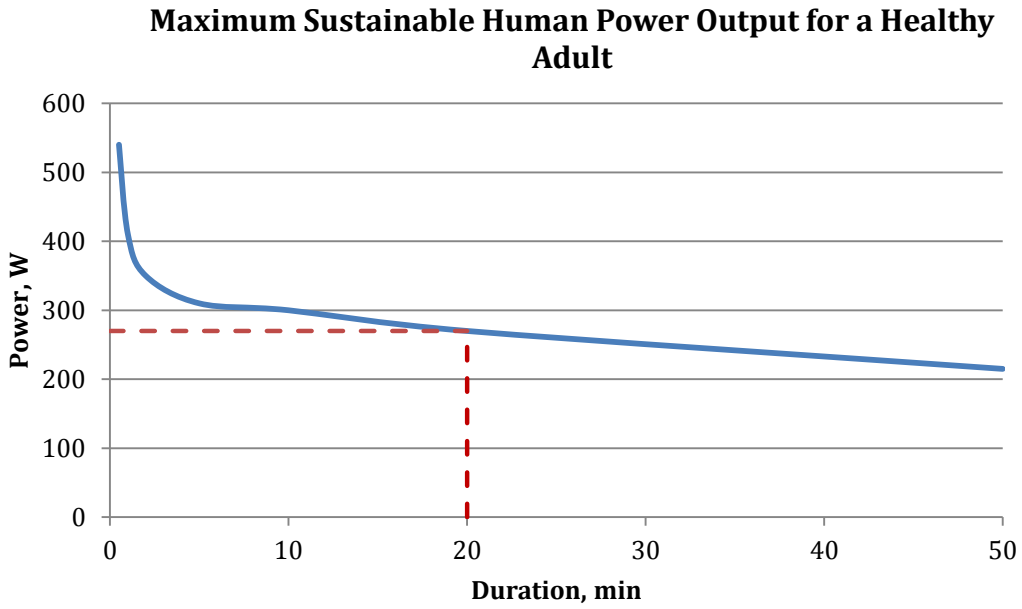

Figure 22 Maximum sustainable human power output. (Wilson, 2004).

Comparing the study to the system simulations, the average power requirement for the purification system using the two Black Max membranes falls well below the maximum sustainable power output for a human over 10 minutes of pedaling.

Altogether, the purification system was designed to remove biological contamination and total dissolved solids. However, two important points must be noted. Careful examination of the specification sheet for the reverse osmosis membranes indicates that the membranes are designed for a maximum feedwater concentration of 2000 ppm total dissolved solids, but the team wanted to test the system up to around 4500 ppm. After consultation with the staff at EMS Water Systems, the team determined that the primary reason for the limitation of 2000 ppm was that for greater concentrations, dissolved solids could deposit on the membrane surface and cause it to foul. The team found that there were commercially available membranes similar in size and capacity to the chosen Black Max membranes but made with different material that could withstand greater concentrations of dissolved solids, but that these membranes would have to be shipped from farther away and would add significant shipping costs and downtime to the project. For the purposes of this project, the team used the Black Max membranes beyond their recommended operating limits of dissolved solids. The staff at EMS indicated that fouling effects would likely not occur during the short period of time the team required the membranes for the testing phase of the project. Future iterations of the design would replace the Black Max membranes with membranes specifically designed for brackish water applications. It is not expected that this change would

greatly affect the performance of the system, but would significantly increase the system's longevity and durability.

Another important point is that the Black Max membrane specification recommends that the membranes be used with feedwater that has no microbiological activity. The team expects that the primary cause for this concern is that as bacteria become trapped within the membrane it can grow and cause bacterial fouling. Some reverse osmosis literature suggests that membranes be shocked with a biocide at certain intervals in order to destroy bacterial growth in the system. This biocide could simply be chlorine, although there are other commercially available options (Kucera, 2010). During testing, the team encountered no difficulties due to bacterial fouling (though testing was only performed over a period of a few weeks), and proved reliably that the system was completely removing all traces of bacterial contaminants.

The following section of this report will outline the testing done to characterize the system performance and prove that the system can meet the design requirements.

5. Testing

5.1. Objectives

There were 3 main objectives associated with testing:

1. To measure the output flow rate of permeate for varying influent water qualities, recovery rates, and pedaling speeds
2. To verify that the power requirements of the system can be achieved using human power
3. To demonstrate the effectiveness of the system to purify water

5.2. Materials and Equipment

Table 7 below summarizes the list of materials and equipment that were utilized throughout the testing sessions:

Table 7 Materials and equipment required for testing

Quantity	Equipment
1	Tachometer
2	Digital multi-meter
1	Digital thermometer
2	Digital scale
3	18.5 L water jug
1	Stop watch
1	¼ HP, 90 Volts, 3.0 Amp DC Motor
1	Motor speed controller
12	500mL Nalgene bottles
9	500mL sterile glass bottles
-	TDS probe and measurement setup
-	Colilert water test setup
-	Total Organic Compounds/Dissolved Organic Compounds water test setup

5.3. Procedures

The equipment listed in Table 7 was used to measure system parameters required to characterize the system performance and demonstrate its effectiveness at meeting the design requirements. For all water quality testing, the team was given access to the equipment at the Centre for Water Resources Studies' water quality lab. The staff at the lab helped the team to set up the various tests required to validate the effectiveness of the purification system. The following subsections 5.3.1, 5.3.2, and 5.3.3 summarize the testing procedures corresponding to the different tests performed.

5.3.1. Flow Rate Testing

The design requirement of producing 10 L of clean water in 20 minutes of pedaling required that the system produce at least 0.5 Litres per minute of permeate. To determine whether the system was capable of producing this flow rate, it was tested using the set-up shown in Figure 23 below:

Figure 23 Experimental setup of flow rate testing

Flow rate was measured while varying specific operating parameters. The parameters that were varied included:

1. Motor speed (varied RPM: 1010 rpm, 1130 rpm, 1260 rpm, and 1390 pm)
2. System Pressure (varied from 70 psi – 110 psi in increments of 10 psi)

3. TDS level of water (varied concentration from 100 ppm, 1500 ppm, 3000 ppm, and 4500 ppm)

The motor speed was varied using the variable speed box. A tachometer was used to measure the rpm of the shaft driving the pump. Two multi-meters measured voltage and amperage being drawn by the motor. The recovery rate valve was manually adjusted to modify the system back pressure which was read by the analog pressure gages. The accumulated mass of concentrate and permeate water exiting the reverse osmosis membranes were measured separately by two digital scales. Using a stop watch, the flow rate was calculated based on the difference in mass measured over a measured time interval.

The test set-up detailing the specific measurements is shown in the schematic in Figure 24 below.

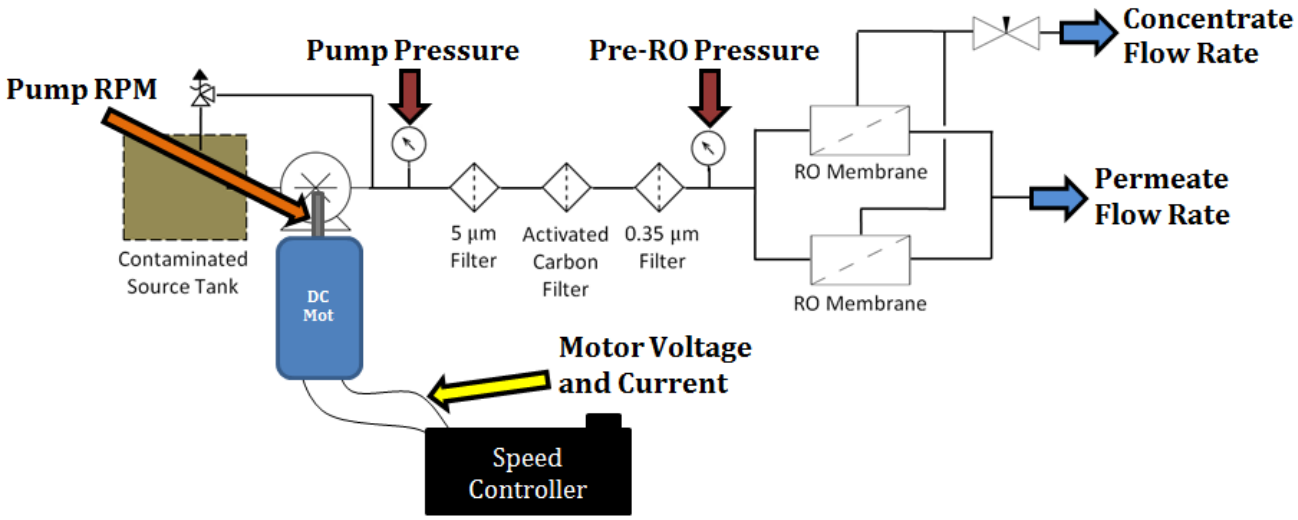

Figure 24 System performance testing set-up. Measurement points designated by arrows.

For the system flow rate tests, the voltage and current drawn by the motor were measured in order to quantify the power consumption of the system under different operating conditions. The power measurements will be discussed in further detail in the following subsection.

For the different tests, a sample of the influent water quality and permeate was collected in the 250 ml Nalgene bottles. These bottles were then taken to the Water Center for Resources Studies to be measured for total dissolved solids. To achieve the different levels of total dissolved solids, table salt was added manually to the jug of water that was feeding the system.

5.3.2. Human Power Testing

The Human Powered Water Purification System was designed so that it may produce 10 L of drinking water after 20 minutes of operation using only human power. To ensure that the bike can be powered only using human power, the entire system was assembled (bicycle and hydraulic circuit) and 2 tests were conducted. The following data was collected at one minute intervals until 10L of clean water were produced:

1. The pedaling speed of the user
2. The system backpressure
3. The accumulated mass of the permeate (clean water)

To measure these parameters, the tachometer, pressure gages, digital scale, and timer were used. Collecting this data produced results that displayed how much clean water can be produced for an average pedaling speed and average system back pressure over the course of 20 minutes. The water quality used for this test was that of lake water (containing approximately 300 ppm TDS). This type of water quality was selected because it is representative of the type of water that may be available as the source water for typical applications of this system.

In order to quantify the power consumption of the system and compare it with the power capabilities of normal humans, the test set-up described in the previous section also incorporated measuring electrical power being drawn by the motor. The team initially intended to use the electrical power measurement to correlate to the human power requirement of the system. However, the team was unable to identify a specification sheet for the DC motor used, and therefore was unable to determine the efficiency of the motor. For the purposes of the power analysis, the electrical power drawn by the motor was used only as a rough indication of the human power requirement. Because of the efficiency of the motor, the electrical power being drawn by the motor is larger than the mechanical power being used by the system to drive the pump. Because of this, using electrical power as an indication of mechanical human power is conservative, and gives only an over-estimate of the mechanical power requirement of the system.

5.3.3. Water Quality Testing

To measure the effectiveness of the system in improving the water quality, the following parameters were measured:

1. Total dissolved solids
2. Presence/absence of total coliform bacteria

3. Presence/absence of E. Coli
4. Total organic carbon (TOC) and dissolved organic carbon (DOC)

Water tests were performed on water collected from three different locations around Halifax, Nova Scotia, Canada. Water was obtained from Lake Banook in Dartmouth, Nova Scotia and from Frog Pond and McIntosh Run at Roaches Pond in Spryfield, Nova Scotia. The team selected these particular lakes for the following reasons:

1. All three lakes were within approximately 20 minutes' drive of Dalhousie University.
2. According to the HRM Lake Water Data, all 3 lakes contained levels of TDS ranging from between 50-300 ppm and contained detectable levels of E. Coli.

It was necessary to confirm that the levels of total dissolved solids in the lakes were within treatable limits of the system before deciding to use the body of water for testing. It was also necessary to confirm that there were detectable levels of E. Coli in the water so that water quality tests could show an initial presence of bacteria in the water before treating it with the system.

To measure total dissolved solids, a TDS probe was used as displayed in Figure 25.

Figure 25 Measuring levels of total dissolved solids in laboratory

Each time the probe was setup to measure TDS of a batch of water samples, the probe was calibrated by inserting it into a known standard solution of 667 ppm. In between samples, the probe was rinsed using ultrapure water to avoid cross contamination and inaccurate measurements between water samples.

To measure bacteria levels, a Colilert Water Test was performed. The Colilert Water Test consists of a test kit which uses a reagent that is mixed in with the water samples as seen in Figure 26 below.

Figure 26 Mixing in the Colilert reagent into the water samples to test for presence of Coliform and E.coli

The reagent is composed of indicators that react with enzymes found in coliform and E. coli to visually alter the colour of the water to indicate either an absence or presence of coliform or E. coli. This test required that each water sample to be incubated at 35°C for 24 hours. The water samples were then taken out of the incubator as seen in Figure 27.

Figure 27 The water samples after 24 hours of incubating at 35°C

The round vessel at the bottom left hand of the above image is a standard against which the results are compared. Water samples that appeared more yellow than the standard after the incubation

period indicated the presence of total coliforms in the source water. Water samples that appeared fluorescent blue when placed underneath an ultraviolet lamp (as seen in Figure 28) indicated the presence of E. coli. Positive detection of E. coli or coliform indicates that there is at least one organism of bacteria present within 100 ml.

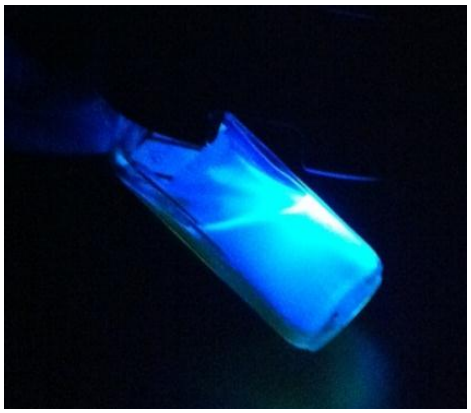

Figure 28 Water sample testing demonstrating presence of E. coli.

The water samples were all collected in sterile glass bottles as per the recommendation of staff at the water treatment lab. For each type of lake water, water was collect at 3 different points. At the inlet of the system (influent), after the pre-treatment stage (Pre-Ro), and at the outlet of the RO membrane (permeate). The test points are shown in the system flow diagram in Figure 29 below.

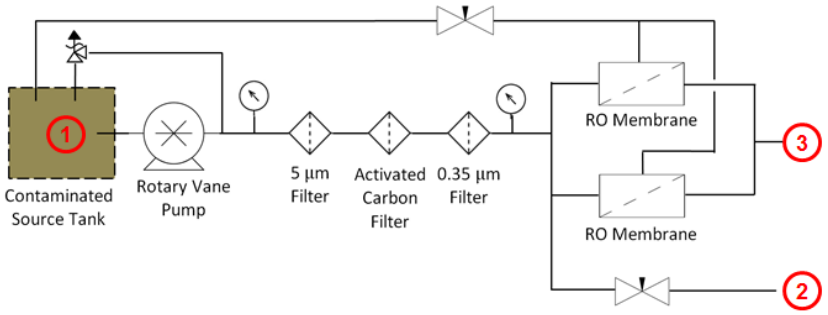

Figure 29 Water quality testing. 1) Source, 2) After Pre-treatment, 3) RO permeate

Finally, total organic carbon and dissolved organic carbon were also measured. The team was shown how to prepare the TOC/DOC samples for analysis, but the staff at the water treatment lab performed the actual analysis. To prepare the sample for TOC and DOC analysis, each water sample was poured into 100 ml sample containers as shown in Figure 30. Four drops of phosphoric acid

were added to each sample. Additionally, for the DOC samples, the water samples were filtered through a 0.45 μm filter sheet so that only dissolved organic carbon was measured.

Figure 30 Samples prepared for TOC/DOC analysis

5.4. Results

The raw data obtained for all the different tests performed may be found in Appendix A. Only a summary of the main results is shown in the following subsections.

5.4.1. Flow rate Results

For the first set of results, clean tap water was filtered through the system to obtain data for system performance. Tap water was measured to contain ~ 70 ppm of TDS. From this, as expected, the flow rate was observed to increase as a function of increased back pressure. So as the recovery rate valve was closed, increasing the system pressure, more flow was observed to penetrate through the RO membranes producing higher permeate flow rates. For this type of water quality, flow rates above 0.5 Lpm were observed for all four pump speeds. As the level of TDS increased, it was expected that the flow rates would shift down. This was confirmed in Figure 31 below.

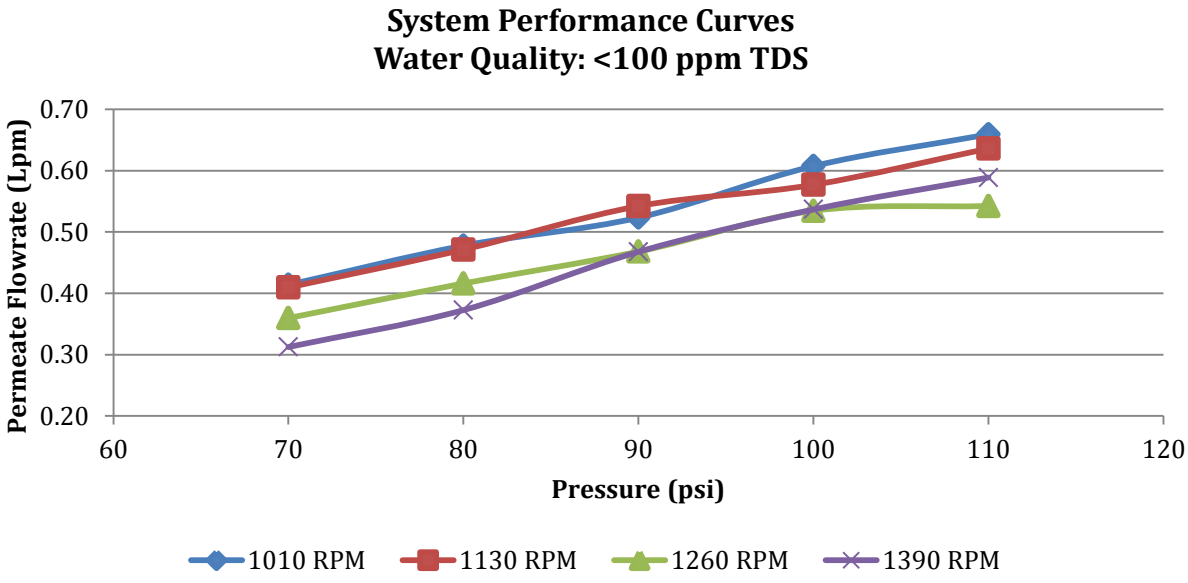

Figure 31 Flow rate VS backpressure for various pump speeds

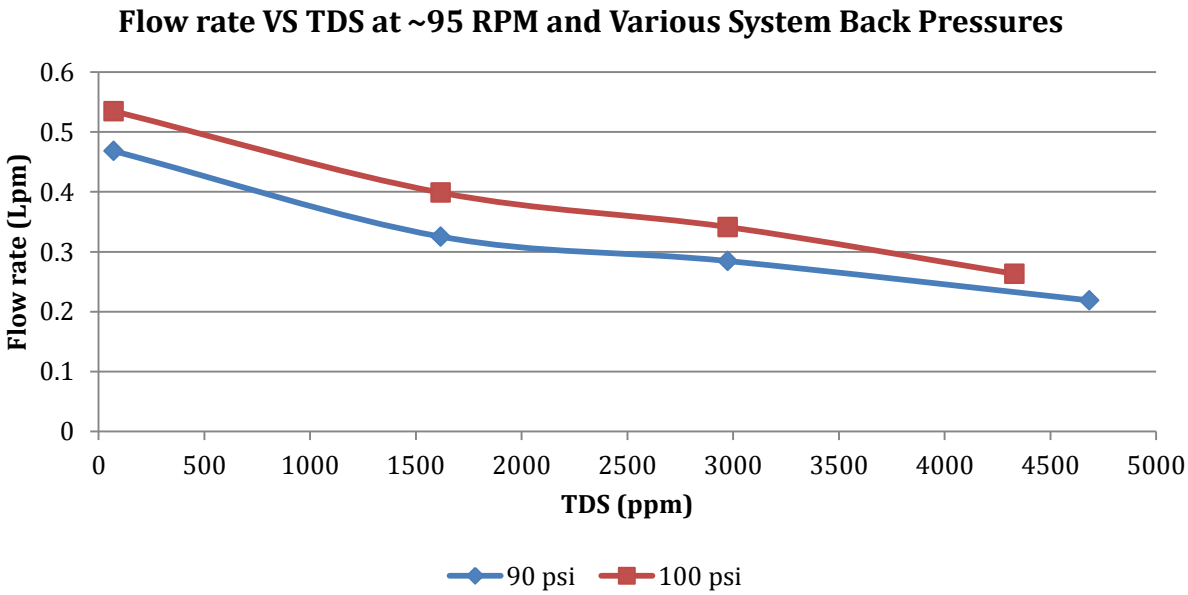

Figure 32 Flow rate VS TDS level for pressures of 90 and 100 psi and ~95 rpm pedal speed

As observed from Figure 32, a drop in flow rate is observed as the level of TDS increases. Also, as the pressure is increased from 90 psi to 100 psi, more flow is observed for all TDS levels. For a system pressure of 100 psi, the flow rate was observed to drop below 0.5 Lpm at a TDS level of approximately 500 ppm. To increase the level of TDS that can be pumped through the system while

maintaining a flow rate of 0.5 Lpm, the curve needs to be shifted upwards corresponding to increasing the system pressure to 110 or 120 psi.

The following subsection summarizes the results of the human power testing.

5.4.2. Human Power Results

Two 20 minute trials were performed to demonstrate that a human can sustainably power the Human Powered Water Purification System for 20 minutes time to produce 10 L of drinking water. One team member pedaled the bike for 20 minutes. The pedaling speed was measured every minute to maintain a constant pedaling speed of ~90 RPM. The results of both tests are shown in Table 8 below.

Table 8 Full 20 minute pedaling test results

Trial 1	Average Pedaling Speed	90 RPM
	Average System Back Pressure	100 psi
	Total Water Purified	**8.2 L**
Trial 2	Average Pedaling Speed	90 RPM
	Average System Back Pressure	120 psi
	Total Water Purified	**9.6 L**

In the two 20 minute trials of pedaling lake water containing approximately 300 ppm of TDS, the recovery rate of the RO membranes was varied to increase the permeate from 8.2 L to 9.6 L. Even though the trial that produced the most amount of water was still 4% under the desired quantity of 10 L, the team believes that it is still possible to achieve 10 L. The team believes that during one test using water from Halifax harbour, the reverse osmosis membranes were slightly fouled because of the high salt concentration of the seawater (~35,000 ppm). The full 20 minute tests were done after seawater was pumped through the system. The system is not designed to handle such high concentration salt water, but thought it was worth testing purely out of interest and curiosity.

Using the first test set-up in which the pump was being driven by a DC motor, the electrical power drawn by the motor was also used to quantify the power requirements of the system. The relation between the permeate flow rate and electrical power to the motor is shown in Figure 33 below.

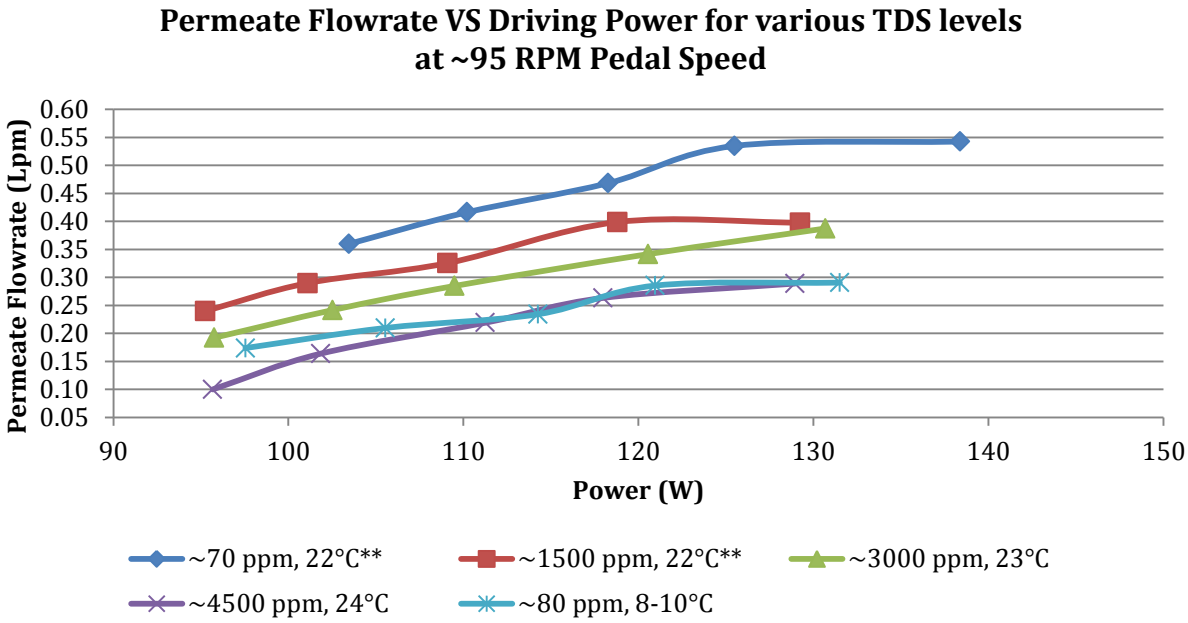

Figure 33 Flow rate VS driving power for various water qualities and ~95 rpm pedal speed

As demonstrated in the plot, the power requirements of the system vary between about 100 and 140 W. This power requirement is well within the capabilities of human power production. As described previously in the report (see Figure 22) a healthy adult is able to produce a maximum of ~270 W over a duration of 20 minutes. The power requirements of the Human Powered Water Purification system fall well below this limit.

One important point to note is that the flow rate of 0.5 Lpm is not achieved for source water with high concentrations of total dissolved solids, but only for relatively fresh water. In the design requirements, the team set out an optional requirement that the system remove total dissolved solids. For this reason, the team is satisfied that the system can achieve the required flow rate for source waters with low total dissolved solids. For more brackish sources, the system is still able to produce a reasonable flow rate in the range of 0.3 Lpm, but somewhat less than the 0.5 Lpm target.

In the following figure, the power requirements of the system for different pedaling speeds are compared to an example of a human power output over a range of pedaling speeds.

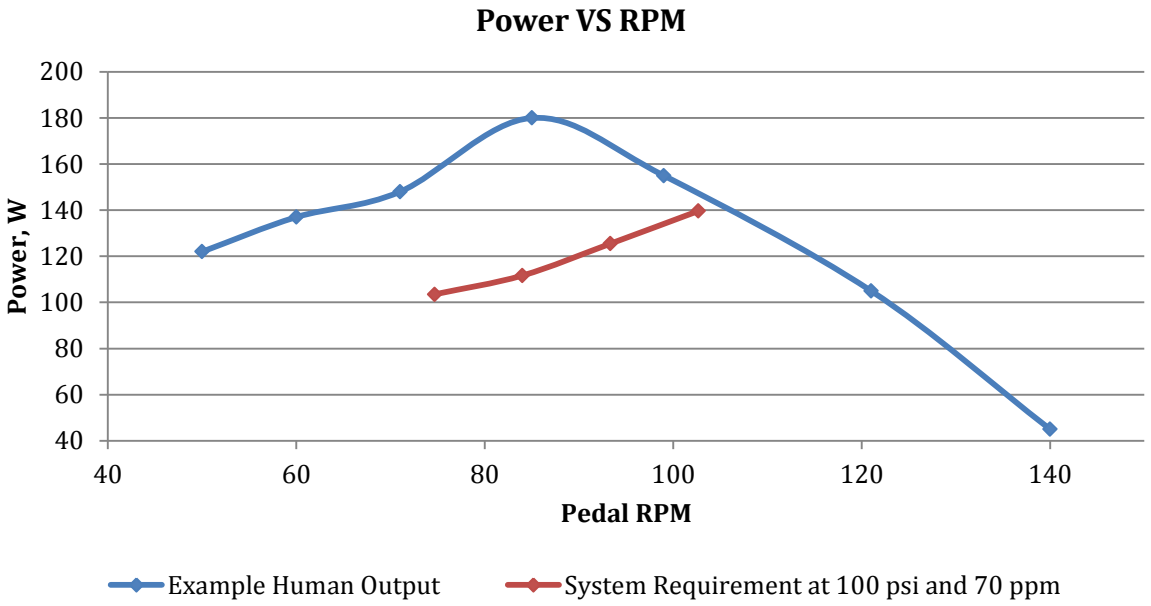

Figure 34 Human power capability compared to system power requirement. Human power capability data obtained from (Wilson, 2004).

As demonstrated by the figure, the power consumption of the system for this particular operating condition falls within the capabilities of human power. It should be noted that quality of water that can be treated is limited by human power capabilities, the level of TDS in the water, and the pressure limitations on the system. The higher the TDS, the higher the pressure required to force the water through the reverse osmosis membrane. Since power is proportional to the flow rate multiplied by the pressure produced by the pump, higher TDS water would require that the system flow rate be decreased in order to keep the power requirements within human capabilities.

5.4.3. Water Quality Results

For the 3 different water sources, the Colilert Water Test was completed and showed that the permeate water in all cases was absent of coliform and E. coli. A summary of results from the 3 different lakes is summarized in Tables 9, 10, and 11 below.

Table 9 Water quality bacterial test results summary for Banook Lake

Lake Banook	E. Coli	Coliform	TDS
Influent	Present	Present	507 ppm
Pre-RO	Absent	Present	491 ppm
Permeate	Absent	Absent	10 ppm

Table 10 Water quality bacterial test results for Fog Pond

Frog Pond	E. Coli	Coliform	TDS
Influent	Present	Present	374 ppm
Pre-RO	Present	Present	---
Permeate	Absent	Absent	47 ppm

Table 11 Water quality bacterial test results for McIntosh Run

McIntosh Run	E. Coli	Coliform	TDS
Influent	Absent	Present	212 ppm
Pre-RO	Absent	Present	---
Permeate	Absent	Absent	18 ppm

The Colilert Water test is sensitive enough to detect a single organism of E. coli or coliform within a 100 ml sample. Therefore, results that yield "Absent" prove that the water contains no E. coli or coliform in every 100 ml sampled. For all 3 lakes, it is demonstrated that any levels of E. coli or coliform were removed in the permeate water. Interestingly for Lake Banook, it is actually observed that E. coli was removed in the pre-RO stage. This suggests that the pre-treatment stage of filters (before the RO membranes) were successful in removing E. coli. However, in Frog Pond, E. coli was still present at the Pre-RO stage and was only removed after penetrating through the reverse osmosis membranes. These conflicting results may be attributed to the fact that the ultra filter in the pre-treatment stage of the system is specified to filter material at 0.35 microns nominal. E. coli which may have sizes in the range of 1 micron (Abedon, 1998) may still be getting through since the nominal rating of 0.35 microns is not an absolute pore size. This demonstrates that the pre-treatment stage cannot be relied on and guaranteed to remove micro-bacterial organisms. However, the permeate out of the RO membranes proves to be successful in removing all pathogens. Furthermore, for TDS there is approximately a 98% reduction in TDS in Lake Banook

water, while only ~90% reduction in TDS for the Frog Pond and McIntosh samples. The large drop in salt rejection between tests is attributed to the fact that in between testing sessions between Lake Banook and the 2 other lakes, the team attempted passing through Halifax Harbour water through the system which contained levels of 35,000 ppm. This temporarily clogged the reverse osmosis membranes and evidently had an effect in decreasing the effectiveness of the membranes to reduce TDS levels. This is expected though because as the RO membranes are utilized they slowly foul until the flow rate they produce decreases and the pores within them clog up.

According to the Canadian drinking water guidelines, potable water cannot have any levels of E. coli or coliform in it. This test confirms that microbiologically contaminated water has been cleaned to levels that meet this guideline. Furthermore, potable water tends to be produced with levels of TDS less than 500 ppm. Evidently, the reject of TDS levels in the system is capable of reducing TDS levels to below this threshold limit of 500 ppm.

The last set of results that will be discussed are the TOC/DOC results. Due to the time constraints, this test was only performed on water samples obtained from Lake Banook. Table 12 displays the results that were gathered.

Table 12 Water quality bacterial test results for Frog Pond

	TOC [mg/L]	DOC [mg/L]
Influent	2.4685	2.411
Pre-RO	2.6065	2.518
Permeate	0.21485	0.25735

From the results of the TOC/DOC test, a 90% reduction is observed in both levels of TOC and DOC. Interestingly though, an initial increase in TOC and DOC is observed at the Pre-RO stage. This suggests that there is actually an increase in organic material as the water passes through the pre-treatment stage of the system. This makes sense, because it is possible that organic material in the activated carbon filter is leaching into the water thereby increasing the levels of TOC/DOC. However, after the reverse osmosis membranes, the permeate appears to have levels of organic compounds below 0.3 mg/L. According to the Environmental Protection Division of the Ministry of Environment of British Columbia “the water quality criteria for total organic carbon are 2 mg/L for treated water and 4 mg/L for source water”. In this test, the system was proven to be capable of reducing TOC/DOC levels below the 2 mg/L guideline.

6. Budget

The allocated budget provided to Team 15 by the Mechanical Engineering Department was $1200. The total cost of this project was **$1112.30** .

A general breakdown of the budget is summarized in Table 13 categorized by major components of the system. A detailed itemized budget is provided in Table 14.

Table 13 Summarized budget categorized by major components

Major Components	Price
Drive train (Sprockets, hubs, chain, etc.)	$ 185
Frame (Metal, fasteners, etc.)	$ 230
Hydraulic Components (Compression fittings, tubes, valves, etc.)	$ 285
Membranes and Filters	$ 285
Pump	$ 135
Total	**$ 1110**

Table 14 Detailed budget

Qty	Item	Price	Subtotal	Supplier
Drive Train				
1	Pedals	15.00	15.00	Ideal Bikes
1	45 Tooth Sprocket	10.49	10.49	Mcmaster Carr
1	hub-w 5/8" bore	5.49	5.49	Mcmaster Carr
1	35 tooth sprocket (#35, 5/8"bore)	29.07	29.07	McMaster Carr
1	10 tooth sprocket (#35, 5/8"bore)	9.47	9.47	McMaster Carr
2	3/16 x 12" key stock	2.29	4.58	Princess Auto
1	chain roller #35 10ft	15.99	15.99	Princess Auto
6	bearings	3.99	23.94	Princess Auto
1	sprocket weld-on 35v16	2.99	2.99	Princess Auto
1	sprocket weld-on 35w60	15.49	15.49	Princess Auto
1	hub-w 5/8" bore	5.49	5.49	Princess Auto
1	hub-v 5/8" bore	4.49	4.49	Princess Auto
1	connecting link	1.99	1.99	Princess Auto
1	L075 x 5/8 Jaw Coupling	4.07	4.07	Wajax
1	jaw coupling spider	1.15	1.15	Wajax
1	L075 x 7/16 Jaw Coupling	12.33	12.33	Wajax
Frame				
1	Fastners	12.35	12.35	Canadian Tire
1	Metal	16.29	16.29	Kent Building Supplies
1	Metal	83.55	83.55	Metals-R-Us
1	Metal	17.00	17.00	Metals-R-Us
1	Metal	18.50	18.50	Metals-R-Us
4	2.5" clamp exhausts	2.79	11.16	Princess Auto
1	Fastners	3.74	3.74	Princess Auto
2	1/4" nut	0.05	0.10	Princess Auto
2	1/4" x 1.5" bolt	0.15	0.30	Princess Auto
2	hose clamps 2"	1.19	2.38	Princess Auto
2	2.5" clamp exhausts	2.79	5.58	Princess Auto
1	Zinc assortment of fastners	20.09	20.09	Trans-World Distributing Ltd.
Hydraulic Components				
1	3/8 Tubing	8.39	8.39	Canadian Tire
1	Compression Sleeves (pkg)	6.58	6.58	Canadian Tire
1	Miniature PVC Suction Strainer Fits 3/8 NPT Male, 304 Stainless Steel Screen, Mesh Size 80	2.1	2.1	Mcmaster Carr
1	Nylon Check Valve	15.00	15.00	Mcmaster Carr
25	Choose-A-Color Flexible Nylon Tubing .275" ID, 3/8" OD, .050" Wall Thickness, White	0.85	21.25	McMaster Carr

Qty	Item	Price	Subtotal	Supplier
6	Durable White Nylon Compression Tube Fitting Tee for 3/8" Tube OD	4.14	24.84	McMaster Carr
4	Tube Fitting Adapter for 3/8" Tube OD X 1/4" NPTF Male Pipe	1.48	5.92	McMaster Carr
4	Tube Fitting Adapter for 3/8" Tube OD X 3/8" NPT Male Pipe	1.48	5.92	McMaster Carr
1	Tube Fitting Adapter for 3/8" Tube OD X 3/8" NPT Female Pipe	2.50	2.50	McMaster Carr
2	Tube Fitting Adapter for 3/8" Tube OD X 1/4" NPTF Female Pipe	2.22	4.44	McMaster Carr
1	Self-Aligning Brass Compression Tube Fitting Adapter for 3/8" Tube OD X 1/2" NPTF Female Pipe	6.23	6.23	McMaster Carr
1	Self-Aligning Brass Compression Tube Fitting Adapter for 3/8" Tube OD X 1/2" NPTF Male Pipe	4.06	4.06	McMaster Carr
6	Self-Aligning Brass Compression Tube Fitting Adapter for 3/8" Tube OD X 1/8" NPTF Male Pipe	2.36	14.16	McMaster Carr
0	Miniature PVC Ball Valve 3-Port, NPT Female X Female X Female, 1/4" Pipe Sz	16.14	0.00	McMaster Carr
2	Compact Plastic Needle Valve 1/4" Female NPT X 1/4" Female NPT	20.24	40.48	McMaster Carr
1	Adjustable Bronze Relief Valve Precision, 1/2 NPT Inlet, 1/2 NPT Outlet, 25-175 PSI	25.42	25.42	McMaster Carr
2	Multipurpose Gauge Plastic Case, 2" Dial, 1/4 NPT Bottom, 0-200psi	9.66	19.32	McMaster Carr
1	Breather Vent 1/2 NPT Male, 17 Max SCFM, 7/8" Height	2.74	2.74	McMaster Carr
1	Teflon Tape	0.59	0.59	Northeast Equipment Ltd
2	3/4" x 1/2" sch40 bushing	1.38	2.76	Northeast Equipment Ltd
2	3/8" comp x 1/2" MPT brass fitting	2.52	5.04	Northeast Equipment Ltd
2	3/4" x 1/2" sch40 bushing	1.38	2.76	Northeast Equipment Ltd
2	3/8" comp x 1/2" MPT brass fitting	2.52	5.04	Northeast Equipment Ltd
2	18.9L empty bottles	14.79	29.58	Sobeys
Membranes and filters				
1	RO Membrane housing	13.95	13.95	Atlantic Purification Systems Ltd
1	Ultra filter	18.90	18.90	EMS Water Systems
1	Ultra filter casing	22.03	22.03	EMS Water Systems
2	100 GPD RO Membrane	76.00	152.00	EMS Water Systems
1	carbon block cartridge	3.00	3.00	EMS Water Systems
1	carbon block casing	17.00	17.00	EMS Water Systems
1	Water Filter w/ Blue Bowl, for Particles, 3/8 NPT, 5 GPM	23.17	23.17	McMaster Carr
Pump				

Qty	Item	Price	Subtotal	Supplier
1	70 GPH Rotary Vane Pump	98	98	Simgo
Subtotal			$ 956.24	
Shipping[1]			$ 70.18	
Taxes[2]			$ 85.88	
Total			**$ 1112.30**	

[1]The taxes from the shipped orders (McMaster Carr and Simgo) have been absorbed into this amount
[2]This is a summation of all taxes spent from items purchased locally (all suppliers except McMaster Carr and Simgo)

7. Implementation

This section will present analyses on the economics and sustainability of the Human Power Water Purification System, as well as how it compares to similar designs.

7.1. Economic Analysis

Some research was done into the economics of the human powered water purification system. This section includes financial viability and sustainability of the value of the project to the current economy. The economic analysis compares the cost of the human powered water purification system to the cost of purchasing drinking water in 18.5 L jugs, and cases of 500 ml water bottles.

Assumptions to Economic Analysis:

- No discount rate is considered
- The water consumption rate is 10 liters per day (family of 5) for 10 years
- The RO membranes have to be replaced once a year, whereas cartridge filters have to be replaced twice a year *(Total replacement cost = $225/year)*
- The cost of refilling 18.5 L water tank is $3 and the cost of a 500 ml water bottle is $1.50
- Transportation costs were neglected

Table 15 Economic analysis summary

Water Sourcing Option	10 Year Cost (Present Day Dollars)
Human Powered Water Purification System	$3300
18.5 L jugs	$6000
500 ml bottles	$13,000

7.2. Environmental sustainability

Having done the economic analysis, the design of the system turned out to be also good for the environment. Assuming it is being used by a family living in a cottage in North Preston, Nova Scotia where access to clean water may not be easy, the design can avoid more than 7 tons of greenhouse gas emissions in ten years. The carbon dioxide emissions associated with the production of plastic bottles amounts to 0.195 kg of CO_2 per liter. The amount of water bottles consumed in 10 years by a family of 5 would result in a total of 7000 kg of CO_2.

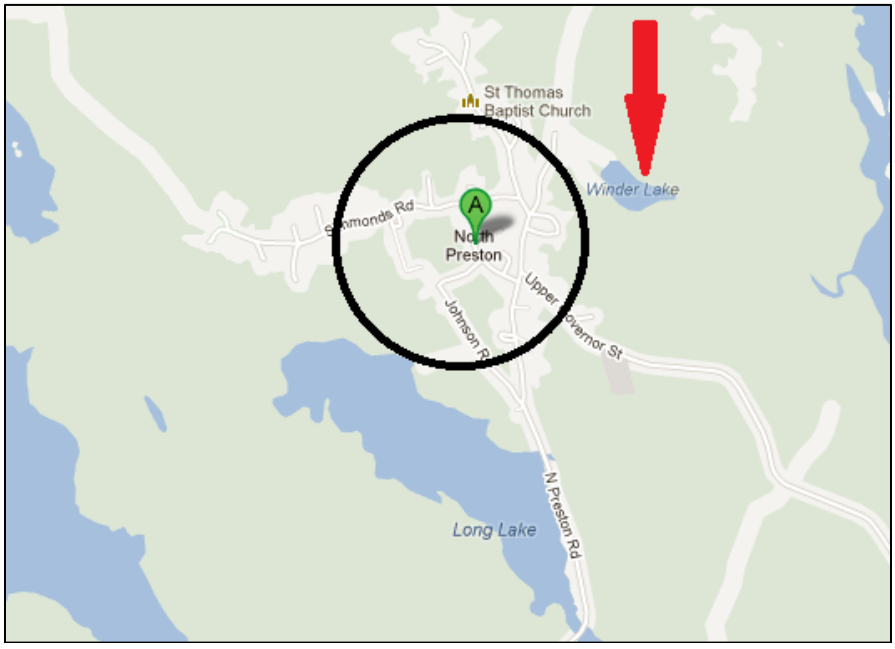

Figure 35 Location of case study

7.3. Design comparison

Initially, the design was inspired by two other human powered water purification systems which are the Aquaduct (Inhabitat, Web.) and the Pedal Powered Human Ultrafiltration Unit (World Wide Water, Web.). Our group succeeded to make the design more powerful than the aforementioned designs in treating water.

The Aquaduct is a pedal-powered concept vehicle that transports, filters, and stores water for the developing world. As the rider pedals, a pump attached to the pedal crank draws water from a large holding tank, through a carbon filter, to a smaller, clean tank. This design cannot kill E.Coli bacteria. It uses a carbon filter for the water treatment.

Figure 36 The Aquaduct

The Pedal Powered Human Ultrafiltration Unit is capable of delivering microbiologically pure water from fresh water sources. The treated water may contain a wide range of pathogens and is treated using an ultrafiltration membrane.

Figure 37 The Pedal Powered Human Ultrafiltration Unit

A comparison of the Human Powered Water Purification unit with the abovementioned designs is summarized in Table 16 below.

Table 16 Design comparison of different water purification systems

Design	Microbacterial removal?	TDS removal?	Flow rate (Lpm)	Price
	No	No	?	?
	Yes	No	14	?
	Yes	Yes	0.50	$1100

8. Conclusion

The Human Powered Water Purification System succeeded in meeting the design requirements, with the exception of marginally meeting the flow rate requirement. The design requirements and achievements are summarized in the table below.

Table 17 Summary of achieved design requirements

Category	Requirement	Achieved
Power	Essential	
	• Mechanically human powered	• Yes
	Optional	
	• Can be powered by only one person	• Yes
Capacity	Essential	
	• 10 L of water after 20 minutes of operation	• 9.6 L in 20 min
Water Quality	Essential	
	• Reduce bacteria, viruses to potable level	• Coliform and E. Coli completely removed
	Optional	
	• Reduce dissolved solids to potable level	• 94% TDS rejection rate
Physical	Essential	
	• Weight less than 40 kg	• 31.4 kg
	• Not to exceed 1 m^3 envelope volume	• 0.99 m^3
Cost	Essential	
	• Prototype cost < $1200	• $1110
	Optional	
	• Projected product fabrication cost in quantity should not exceed $200	• Unexamined

With regards to the capacity requirement of 10L, the system was capable of producing 9.6 L of water, 4% under the desired quantity of 10 L. The team believes that they were not able to surpass the 10 L requirement because at an earlier testing session, one test was performed using water from Halifax harbour. The team suspects that the reverse osmosis membranes were slightly fouled because of the high salt concentration of the seawater (~35,000 ppm). Furthermore, earlier testing sessions confirmed that the system can produce flow rates higher than 0.5 Lpm.

Future iterations of the design could improve in several areas:

- The residential reverse osmosis membranes should be replaced with membranes specifically designed for brackish water applications in order to reduce the possibility of membrane fouling and increase the longevity of the system.
- A third reverse osmosis membrane in parallel would increase the total flow that the system can produce (up to 0.75 Lpm). With the increased capacity, the system would also require a larger pump.
- The water quality of the system permeate water should be tested for a broader variety of contaminants. The levels of total coliforms and total dissolved solids could be supplemented with measurements of the levels of specific heavy metals and chemicals.

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Appendix A Raw Data

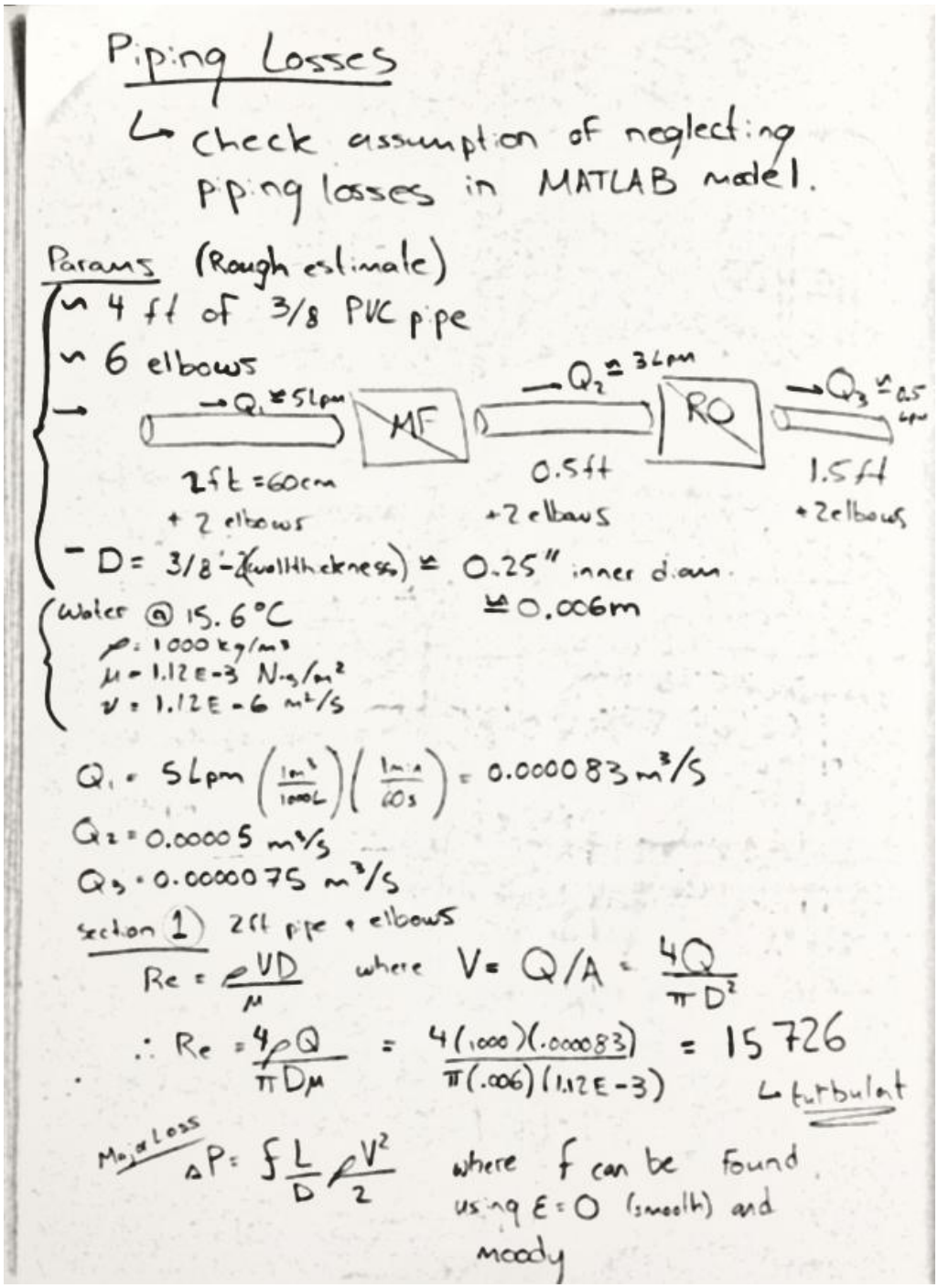
RPM	Pressure (psi)	Concentrate Initial Mass (kg)	Permeate Initial Mass (g)	Current (Amp)	Voltage (V)	Concentrate Final Mass (kg)	Permeate Final Mass (kg)	time interval (sec)	Concentrate Flow rate (L/min)	Permeate Flow rate (L/min)	Recovery Rate	TDS Initial	TDS Final	Batch Temp (°C)
1008	70	8.6	860	2.7	29.41	9.8	1100	34.8	2.07	0.41	0.17	71.80	5.50	25.00
1008	80	12.6	750	2.82	28.96	13.7	1000	31.4	2.10	0.48	0.19	71.80	3.70	25.00
1008	90	1.7	580	3.18	29.73	2.8	860	32.1	2.06	0.52	0.20	71.80	4.30	25.00
1008	100	9.6	812	3.45	30	10.6	1140	32.4	1.85	0.61	0.25	71.80	4.70	25.00
1008	110	12.4	660	3.8	30.38	13.7	1150	44.6	1.75	0.66	0.27	71.80	3.30	25.00
1134	70	9.1	490	2.72	32.47	10.5	705	31.5	2.67	0.41	0.13	71.80	5.60	24.00
1134	80	13.4	660	2.9	32.74	14.7	920	33.1	2.36	0.47	0.17	71.80	2.70	24.00
1134	90	17.9	800	3.14	33.01	19.2	1100	33.2	2.35	0.54	0.19	71.80	2.50	24.00
1134	100	3	850	3.38	33.04	4.2	1150	31.2	2.31	0.58	0.20	71.80	2.90	24.00
1134	110	6.4	750	3.63	33.32	7.6	1102	33.2	2.17	0.64	0.23	71.80	2.60	24.00
1260	70	5.6	560	2.85	36.3	7.2	753	32.2	2.98	0.36	0.11	71.80	5.60	22.00
1260	80	9.8	580	3.02	36.49	11.4	804	32.3	2.97	0.42	0.12	71.80	3.80	22.00
1260	90	13.94	594	3.24	36.5	15.4	853	33.2	2.64	0.47	0.15	71.80	2.40	22.00
1260	100	17.5	1048	3.41	36.8	19	1326	31.2	2.88	0.53	0.16	71.80	2.90	22.00
1260	110	2.7	718	3.74	37	4.1	1010	32.3	2.60	0.54	0.17	71.80	4.20	19.00
1386	70	7	587	2.79	39.2	8.7	750	31.3	3.26	0.31	0.09	71.80	2.30	19.00
1386	80	11.7	560	3.03	39.6	13.4	760	32.2	3.17	0.37	0.11	71.80	1.80	19.00
1386	90	16.5	569	3.23	39.8	18.2	820	32.2	3.17	0.47	0.13	71.80	5.20	22.00
1386	100	3	680	3.5	39.9	4.5	960	31.3	2.88	0.54	0.16	71.80	2.60	22.00
1386	110	7.7	807	3.7	40.1	9.4	1123	32.2	3.17	0.59	0.16	71.80	1.80	22.00
1008	70	2.9	609	2.72	29.16	4.1	768	34	2.12	0.28	0.12	1731	17.1	22.00
1008	80	6.6	524	2.88	29.36	7.7	679	31.2	2.12	0.30	0.12	1731	79	22.00
1008	90	10.4	522	3.11	29.75	11.5	702	31.4	2.10	0.34	0.14	1731	129.2	22.00
1008	100	13.5	575	3.4	29.86	14.6	779	31.3	2.11	0.39	0.16	1731	60.00	22.00
1008	110	8.5	584	3.64	30.17	9.6	824	31.2	2.12	0.46	0.18	1589	83.70	23.00

1134	70	11.6	1138	2.65	33.48	13.1	1303	34.1	2.64	0.29	0.10	1589	83.70	23.00
1134	80	2.5	442	2.92	32.87	3.8	621	32.4	2.41	0.33	0.12	1637	69.50	24.00
1134	90	5.4	841	3.13	32.94	6.6	1034	31.3	2.30	0.37	0.14	1637	69.50	24.00
1134	100	8	1268	3.36	32.94	9.3	1519	33.4	2.34	0.45	0.16	1637	69.50	24.00
1134	110	10.8	1833	3.66	33.35	12	2091	31.3	2.30	0.49	0.18	1637	69.50	24.00
1260	70	8.4	789	2.67	35.67	10.1	920	32.8	3.11	0.24	0.07	1617	64.60	22.00
1260	80	11.5	1060	2.84	35.6	13.1	1215	32.1	2.99	0.29	0.09	1617	64.60	22.00
1260	90	14.5	1368	3.03	36	16.1	1548	33.2	2.89	0.33	0.10	1617	64.60	22.00
1260	100	17.3	1700	3.3	36	18.7	1902	30.4	2.76	0.40	0.13	1617	64.60	22.00
1260	110	2.7	474	3.56	36.3	4.2	694	33.2	2.71	0.40	0.13	1470	61.20	21.00
1386	70	6.4	927	2.74	39.1	8.2	1066	31.3	3.45	0.27	0.07	1470	61.20	21.00
1386	80	6.7	1582	2.95	39.05	8.5	1750	32.2	3.35	0.31	0.09	1457	48.00	25.00
1386	90	13.3	1580	3.16	39.2	15	1785	32.4	3.15	0.38	0.11	1470	61.20	21.00
1386	100	9.9	1915	3.37	39.3	11.4	2150	31.3	2.88	0.45	0.14	1457	48.00	25.00
1386	110	13.1	2440	3.65	39.5	14.6	2720	32.3	2.79	0.52	0.16	1457	48.00	25.00
1134	70	2.7	188	2.68	32.64	4.1	298	31.4	2.68	0.21	0.07	3369	116.5	22.00
1134	80	5.2	395	2.89	32.7	6.6	519	32.2	2.61	0.23	0.08	3369	116.5	22.00
1134	90	7.7	633	3.11	32.9	9	775	31.3	2.49	0.27	0.10	3369	116.5	22.00
1134	100	10.2	928	3.36	33.05	11.5	1094	31.2	2.50	0.32	0.11	3369	116.5	22.00
1134	110	12.6	1255	3.65	33.3	13.8	1448	32.2	2.24	0.36	0.14	3369	116.5	22.00
1260	70	2.9	209	2.66	36	4.5	306	30.3	3.17	0.19	0.06	2974	127.9	23.00
1260	80	6.6	461	2.88	35.6	8.2	587	31.3	3.07	0.24	0.07	2974	127.9	23.00
1260	90	10.5	795	3.05	35.9	12.1	943	31.2	3.08	0.28	0.08	2974	127.9	23.00
1260	100	13.1	1066	3.33	36.2	14.8	1260	34.1	2.99	0.34	0.10	2974	127.9	23.00
1260	110	1.6	205	3.59	36.4	2.9	407	31.3	2.49	0.39	0.13	3300	172.9	23.00
1386	70	6.2	695	2.7	39	8.3	812	36	3.50	0.20	0.05	3300	172.9	23.00
1386	80	10.1	921	2.88	39.1	11.7	1044	30.4	3.16	0.24	0.07	3300	172.9	23.00
1386	90	2.9	258	3.11	38.9	4.7	413	32.3	3.34	0.29	0.08	3374	119.7	23.00
1386	100	6.5	614	3.34	39.3	8.2	788	32.2	3.17	0.32	0.09	3374	119.7	23.00

1386	110	10.3	1045	3.57	39.5	11.9	1253	32.3	2.97	0.39	0.12	3374	119.7	23.00
1134	70	1.6	154	2.73	32.73	3.4	250	40.47	2.67	0.14	0.05	4659	231	24.00
1134	80	5.5	371	2.92	32.5	7	466	32.14	2.80	0.18	0.06	4659	231	24.00
1134	90	9	620	3.15	33	10.5	740	32.6	2.76	0.22	0.07	4659	231	24.00
1134	100	12.3	920	3.34	33.19	13.9	1070	32.58	2.95	0.28	0.09	4659	231	24.00
1134	110	10.2	598	3.61	3.54	11.5	770	30.9	2.52	0.33	0.12	4103	192	24.00
1260	70	3.2	151	2.68	35.7	4.8	202	30.66	3.13	0.10	0.03	4685	295	24.00
1260	80	6.7	287	2.84	35.86	8.4	380	34.09	2.99	0.16	0.05	4685	295	24.00
1260	90	9.9	475	3.09	36	11.4	589	31.25	2.88	0.22	0.07	4685	295	24.00
1260	100	2.5	186	3.27	36.08	4.2	342	35.56	2.87	0.26	0.08	4330	203	24.00
1260	110	6.1	511	3.52	36.63	7.6	665	31.99	2.81	0.29	0.09	4330	203	24.00
1386	70	12.2	607	2.68	38.78	14	688	30.52	3.54	0.16	0.04	3427	322	24.00
1386	80	3	180	2.89	38.7	4.9	289	31.67	3.60	0.21	0.05	3762	172	25.00
1386	90	6.6	408	3.08	39.1	8.4	534	31.2	3.46	0.24	0.07	3762	172	25.00
1386	100	10.3	693	3.28	39.26	12	848	31.48	3.24	0.30	0.08	3762	172	25.00
1386	110	13.7	1007	3.5	39.46	15.3	1175	30.42	3.16	0.33	0.10	3762	172	25.00
1134	70	2.4	157	2.7	32.24	3.8	218	32.39	2.59	0.11	0.04	82.00	84.00	8.00
1134	80	5.9	388	2.93	32.41	7.3	504	32.05	2.62	0.22	0.08	82.00	84.00	8.00
1134	90	8.8	641	3.18	32.7	10.1	770	30.56	2.55	0.25	0.09	82.00	84.00	8.00
1134	100	11.5	914	3.41	33.04	12.9	1060	31.44	2.67	0.28	0.09	82.00	84.00	8.00
1134	110	14.1	1195	3.72	33.46	15.4	1350	30.14	2.59	0.31	0.11	82.00	84.00	8.00
1260	70	5.9	763	2.74	35.6	7.6	856	32.13	3.17	0.17	0.05	73.00	4.60	8.00
1260	80	9.3	965	2.94	35.9	10.9	1077	32.06	2.99	0.21	0.07	73.00	4.60	8.00
1260	90	13	1225	3.18	35.93	14.5	1345	30.76	2.93	0.23	0.07	73.00	4.60	8.00
1260	100	4.5	460	3.36	36	6.1	608	31.13	3.08	0.29	0.08	89.70	2.60	10.00
1260	110	7.7	765	3.6	36.53	9.3	920	32.01	3.00	0.29	0.09	89.70	2.60	10.00
1260	120	11.5	1198	3.84	36.47	13	1385	32.58	2.76	0.34	0.11	89.70	2.60	10.00
1386	70	1.8	206	2.69	38.59	3.6	307	31.35	3.44	0.19	0.05	88.30	3.00	10.00
1386	80	5.3	425	2.88	38.76	7	543	30.56	3.34	0.23	0.06	88.30	3.00	10.00

1386	90	9.5	723	3.1	38.93	11.3	857	31.83	3.39	0.25	0.07	88.30	3.00	10.00
1386	100	12.8	990	3.33	39.25	14.6	1142	31.89	3.39	0.29	0.08	88.30	3.00	10.00
1386	110	2.3	275	3.6	39.4	4.8	540	45.6	3.29	0.35	0.10	90.60	2.30	11.00
1386	120	6.4	740	3.8	39.4	8.1	937	31.33	3.26	0.38	0.10	90.60	2.30	11.00

Appendix B Design Calculations


Piping Losses
↳ check assumption of neglecting piping losses in MATLAB model.
Params (Rough estimate)
~ 4 ft of 3/8 PVC pipe
~ 6 elbows
→ Q1 ≈ 5Lpm
MF
→ Q2 ≈ 3Lpm
RO
→ Q3 ≈ 0.5 Lpm
2ft = 60cm
+ 2 elbows
0.5ft
+2 elbows
1.5ft
+2 elbows
- D = 3/8" - 2(wall thickness) ≈ 0.25" inner diam.
≈ 0.006m
Water @ 15.6°C
ρ = 1000 kg/m³
μ = 1.12E-3 N·s/m²
ν = 1.12E-6 m²/s
Q1 = 5Lpm (1m³/1000L)(1m/60s) = 0.000083 m³/s
Q2 = 0.00005 m³/s
Q3 = 0.0000075 m³/s
section (1) 2ft pipe + elbows
Re = ρVD/μ where V = Q/A = 4Q/πD²
∴ Re = 4ρQ/πDμ = 4(1000)(.000083)/π(.006)(1.12E-3) = 15726
↳ turbulent
Major Loss
ΔP = f L/D ρV²/2 where f can be found using ε = 0 (smooth) and moody

$f = 0.027$

$$\therefore \Delta P = \frac{(0.027)}{2}\left(\frac{0.6m}{(.006m)}\right)(1000)\left[\frac{4*.000083)}{\pi(.006)^2}\right]^2$$

$\Delta P = 11.63\ kPa \simeq 2\ psi$

↳ negligible

Elbows:

$$\Delta P = \frac{K_L}{2}\rho V^2$$

for a regular 90° threaded pipe elbow:

$K_L \simeq 1.5$

$$\therefore \Delta P = \frac{1.5}{2}(1000)\left(\frac{4*.000083}{\pi(.006)^2}\right)^2 = 6.5\ kPa \simeq 1\ psi$$ for each elbow

↳ since losses through the longest, highest flow velocity section of piping are on the order of 5 psi, the whole piping line can be considered negligible in terms of losses compared to the membranes

$\Delta P_{piping} < 10\ psi$

Process Calc

2.5×21" Low E. Brackish water membrane (AMI membranes)

Ratings

$Q_p = 1703$ Lpd $= 1.18$ Lpm

① $\Delta P = 150$ psi (trans-membrane)

② $T = 25°C$

$r = 15\%$

TDS = 2000 ppm

Find ΔP for $Q_p = 0.5$ Lpm at 25°C and 4000 ppm
↳ $C_T = 1$

$$\Delta P = \frac{Q_p}{Q_{p,rated}} \cdot C_T \left(\Delta P_{rated} - \frac{TDS_{rated}}{100} \right) + \frac{TDS}{100}$$

↳ osmotic pressure (approx).

$$\Delta P = \frac{0.5 \text{ Lpm}}{1.18 \text{ Lpm}} (1) \left(150 \text{ psi} - \frac{2000 \text{ ppm}}{100} \right) + \frac{4000 \text{ ppm}}{100}$$

$\Delta P = 95$ psi

* Assume 10 psi piping losses
* Assume 10 psi MF pressure drop

$\therefore P_{pump} = 95 + 10 + 10 = \boxed{115 \text{ psi}}$

pump Flow:

$$Q_{pump} = Q_{permeate} \left(\frac{1}{r_{RO}} \right) \left(\frac{1}{r_{MF}} \right)$$

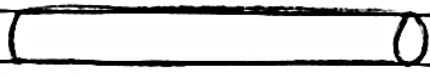
↳ recoveries of membrane

$$Q_{pump} = 0.5 \text{ Lpm} \left(\frac{1}{.15} \right) \left(\frac{1}{.90} \right) = \boxed{3.7 \text{ Lpm}}$$

Pump Drive Assembly

Nov. 24, 2012

Shaft calculations:



$$\tau = \frac{Tr}{J} \Rightarrow \tau_{max} = \frac{16T}{\pi D^3}$$

Torque:

Max Power ≈ 150 W

$$\text{Power} = F * |\vec{v}|$$

$$150W = F * \omega * r$$

$$F = \frac{150}{90\,\text{rpm} * \frac{2\pi\,\text{rad}}{\text{rot}} * \frac{\text{min}}{60\,\text{sec}} * 6 * \frac{1.38\,\text{in}}{2}\left(\frac{0.0254\,\text{m}}{\text{in}}\right)}$$

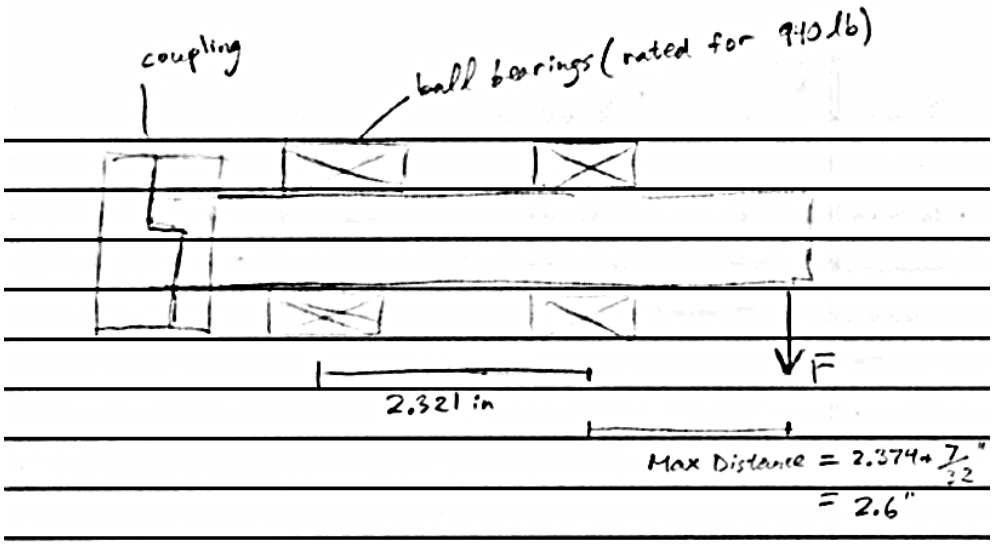
$$F = 152\ N$$

$$T = F * r = 152\,N * \frac{1.38\,\text{in}}{2} * \frac{0.0254\,\text{m}}{\text{in}}$$

$$T = 2.65\ N\cdot m$$

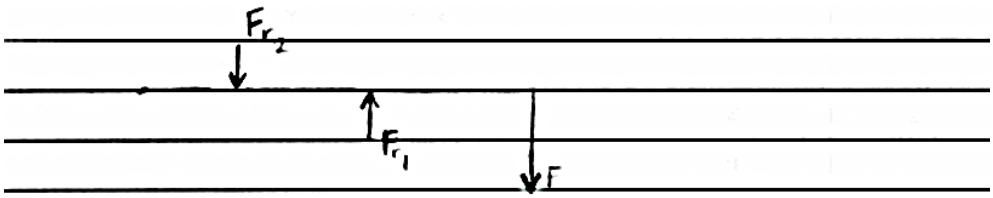
$$\tau_{max} = \frac{16 * 2.65\,N\cdot m}{\pi\left[(0.625\,\text{in})\left(\frac{0.0254\,\text{m}}{\text{in}}\right)\right]^3}$$

$$\tau_{max} = 3.4\ MPa$$



Max Distance = $2.374'' + \frac{7}{32}''$

$= 2.6''$



* Neglect radial force against coupling.

$\therefore F_{r_2} > F_{r_2}|_{actual}$

$F_{r_1} > F_{r_1}|_{actual}$

} more conservative

$\circlearrowleft^{+} \sum M_1 = -F(2.6\,in) + F_{r_2}(2.321\,in) = 0$

$$F_{r_2} = \frac{F(2.6\,in)}{2.321\,in}$$

$$F_{r_2} = (152\,N)\left(\frac{0.225\,lb}{1\,N}\right)\left(\frac{2.6\,in}{2.321\,in}\right)$$

$$F_{r_2} = 38.3\,lb$$

$\sum F_y = 0$

$$F_{r_1} = F_{r_2} + F$$

$$= 38.3\,lb + 152\,N\left(0.225\frac{lb}{N}\right)$$

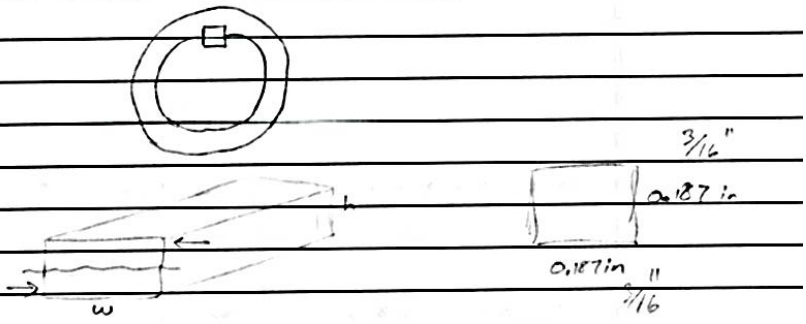
$$= 72.5\,lb$$

Bearing 1 → $F_{r_1} \approx 73\ lb$ $F_{max} = 940\ lb$

Bearing 2 → $F_{r_2} \approx 40\ lb$ $F_{max} = 940\ lb$

∴ safe

Shaft key



Shaft torque capacity, $T = \frac{\pi d^3}{16}(0.75 S_y)$ (a)

Torque that may be transmitted by compressive forces acting on the side of the key, $T = S_y \frac{Ld}{8}\frac{d}{2} = \frac{S_y L d^2}{16}$ (b)

Torque that may be transmitted by key shear, $T = \frac{0.58 S_y L d^2}{8}$ (c)

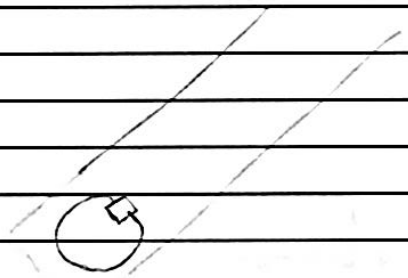
From (a) & (b) → $L = 1.82d$

From (a) & (c) → $L = 1.57d$

∴ if shaft is $\frac{5}{8}$" diameter

minimum length of key = 1.14"

Crank



Crank → Aluminum

Torque that may be transmitted before the crank fails @ the key way.

$$T = \sigma_{compression} * A * r = \frac{S_y L d^2}{16}$$

$$T = 152\,MPa * 0.5\,in\left(\frac{0.0254\,m}{in}\right) * \frac{(0.625 * 0.0254)^2}{16}$$

$$T = 304\,N\cdot m$$

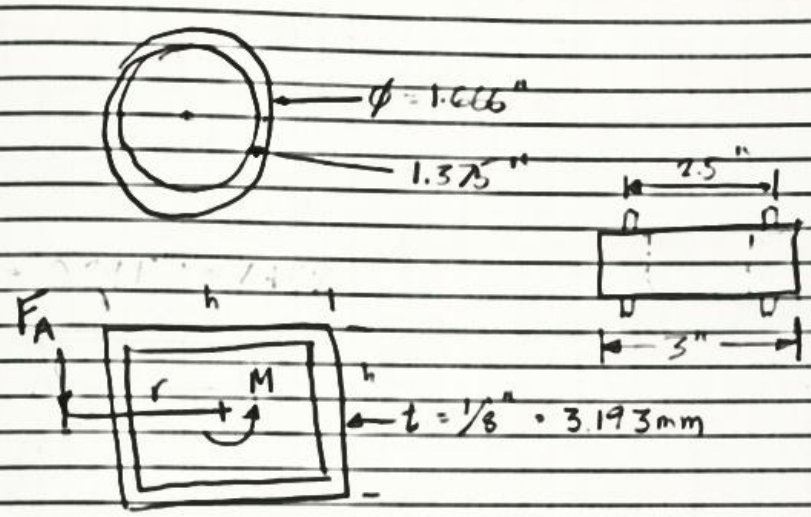
↳ allowable torque

$$T_{applied} = \frac{Power}{\omega} = \frac{150\,W}{90 * \frac{2\pi}{60}} = 15.9\,N\cdot m$$

$$T_{applied} = F * r = 250\,lb * \frac{1N}{0.225\,lb} * 8\,in\left(\frac{0.0254\,m}{in}\right)$$

$$= 226\,N\cdot m$$

STRESS CALCULATIONS Nov 24TH/12



• ASSUMPTIONS MAX WEIGHT = 250lbm
• F_A = 250lbF, r = 1.5" = 1/8', SF = 4

$M = (SF)(F_A)r = 4(250lbF)(1/8) = 125 Ft \cdot lb = 1500 lbin$

$\tau = \frac{T}{2At}$ $A = (h-t)^2 = (2.5-1/8)^2$

$A = 5.64 in^2$

$\tau = \frac{1500 lbin}{2(5.64 in^2)(1/8 in)}$

$\tau = 1063.8 \frac{lbF}{in^2}$

S_y 6061AL = 40000 Psi, τ_{MAX} = 20000 Psi

1063.8 << 20000 Psi (NEGLECTING STRESS CONCENTRATION)

STRESS CALCULATIONS DATE: NOV 24TH/12

ANGLE OF TWIST

FOR THIN WALLED BOX BEAM

$\beta = \frac{T}{4GP^2}\left(\frac{s}{t}\right)$ $P = A = 5.64\,in^2$

$G_{steel} = 25\,84GPa \approx 5200ksi$

$\beta = \frac{1500lb\,in}{4(5200kPsi)(5.64\,in^2)}\left(\frac{(2.5-0.125)^2\,in}{0.125\,in}\right)$

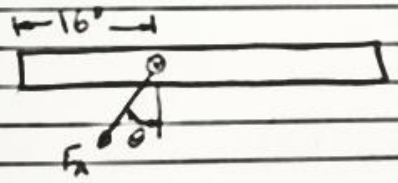
$\beta = 0.000172\ rad/in$

WORST CASE $\theta = 0.000172\left(\frac{42}{2}\right) = 0.00361\,rad = 0.2°$ (SMALL)

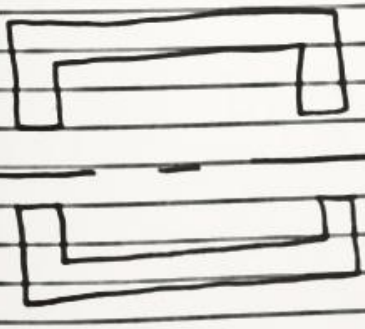
FOR MAIN BEAM (BENDING)

- ASSUME DESIGN LOAD 250lbm, SF = 4

CURRENT ARRANGEMENT



- $F_A = 250lbm(4) = 1000lbm$
  $= 1000lbF$
- $\theta = 45°$
- MODEL AS BEAM WITH 1.666" HOLE

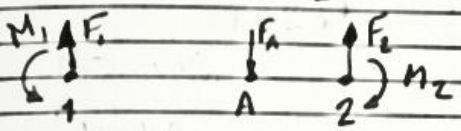


STRESS CALCULATION DATE: NOV 24TH/12

2.5 x 2.5" BOX BEAM, $I = 1.42$ (3/16 WALL THICKNESS)

$\sigma = \frac{MC}{I}$, $M = F_A \cos 45° d$, EVALUATING @ $C = h/2$

$\sigma_{MAX} = L/2 = \frac{42in}{2} = 21in$



$M_1 = -F_A d_A + F_2 L = 0$

$\frac{1000lbF \cos 45° \cdot (42-16)in}{42in} = \frac{F_2 (42in)}{42in}$

$F_2 = 437.7lbF$

SIMILARLY, $F_1 = \frac{1000lbF \cos 45° (16)in}{42in} = 269.4lbF$

$M = 269.4lbF \times (42-16)in = 7003.2 lb \cdot in$

$\sigma = \frac{MC}{I} = \frac{(7000lb\,in)(2.5in/2)}{1.42in^2} = 6160 Psi$

Appendix C Matlab code for process flow simulation

```
%Simulate Flow Through Black Max TFC Membranes

close all; clear all; clc;

%RO Ratings for BME1812R100 BlackMax TFC Membrane
Rec_ro = 0.15;                                  %Rated recovery rate
Q_ro_r = 380/24/60;                             %Lpm, from Lpd
P_ro = 65;                                      %psi
TDS_ro = 500;                                   %ppm
R_ro_tm = P_ro/Q_ro_r;                          %Effective transmembrane
resistance at rated conditions

%Define Water Qualities
TDS = [100 1000 2000 4000];

%System Back Pressures (assume pressure drop across pretreatment is
%negligible)
P = [65:120];

%Calculate Permeate flow for different conditions (assume T = 25 degC,
therefore Ct = 1)
for i = 1:length(TDS)
    Qro(i,:) = (P-TDS(i)/100).*Q_ro_r/(P_ro-TDS_ro/100);
end

%For two RO's in parallel:
Qp = Qro*2;

figure
plot(P, Qp(1,:));
title('Permeate Flow vs. Applied Pressure')
xlabel('Pressure, psi')
ylabel('Permeate Flowrate, Lpm')
grid on
hold on
plot(P, Qp(2,:), 'r'); plot(P, Qp(3,:), 'g'); plot(P, Qp(4,:), 'k');
legend('100 ppm', '1000 ppm', '2000 ppm', '4000 ppm', 'Location',
'NorthWest')

%Pedalling Power
eff_p = 0.35;                   %Pump Efficiency
eff_dt = 0.85;                   %Drivetrain efficiency

%Assume pedaling speed is kept at constant 90 RPM
GR = 13.5;              %Sprocket reduction ratio
w_pump = 13.5*90;       %RPM

%Pump is rated to produce 70 gph (4.4 Lpm) at 1750 RPM, and flow is
approximately
%proportional to rotation speed
Qfeed = 4.4*w_pump/1750;
```

```
%Recovery Rate given by:
Rec = Qp/Qfeed;

P_fluid = Qfeed*P*0.117;                %Fluid power - 0.117 is conversion to
Watts
P_human = P_fluid/eff_p/eff_dt;     %Human Power, W

figure
plot(P_human, Qp(1,:));
title('Permeate Flow vs. Human Power Input')
xlabel('Power, W')
ylabel('Permeate Flowrate, Lpm')
grid on
hold on
plot(P_human, Qp(2,:), 'r'); plot(P_human, Qp(3,:), 'g'); plot(P_human,
Qp(4,:), 'k');
legend('100 ppm', '1000 ppm', '2000 ppm', '4000 ppm', 'Location',
'NorthWest')
```

Appendix D Product Specification Sheets

Fluid-o-Tech
POWER THE FLOW

Brass rotary vane pumps PO 70-400 series

Find out more

The rotary vane pumps, manufactured by Fluid-o-Tech and sold worldwide under the trademark Rotoflow, are volumetric pumps designed for pumping water and moderate aggressive liquids with low flow at high pressure.

Technical features and manufacturing characteristics
The rotary vane pump is brass made with a stainless steel AISI 303 rotor, while the pumping chamber and the vanes are in carbon graphite. The inlet and outlet ports are 3/8" GAS or NPT threaded. The pumps are designed to be directly mounted to the motor with a stainless steel clamp. For different mounting arrangements see our technical info "optional mountings".
Maximum operative temperature: 70 °C (158 F).

Available upon request:
- Viton®/EPDM seals
- Built-in relief valve
- Built-in 100 mesh strainer
- Flange mount
- California AB 1953 compliant brass

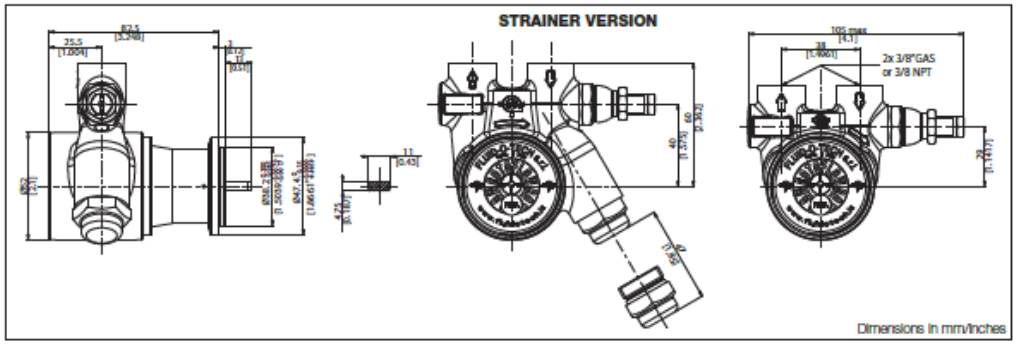
NSF WRAS APPROVED PRODUCT

MAIN APPLICATIONS

• Beverage vending machines	• Water treatment
• Post mix drink dispensers	• Water dispensers
• Espresso coffee machines	• Cooling systems

TECHNICAL INFORMATION

Pump housing material	Brass	Max static pressure	20 bar/290 psi
Pumping chamber	Graphite	Pump weight (clamp mount)	w/o strainer 1.1 kg (2.5 lb)
Ports	3/8" GAS or NPT		w/ strainer 1.3 kg (2.9 lb)
Speed limit	1.725 rpm		

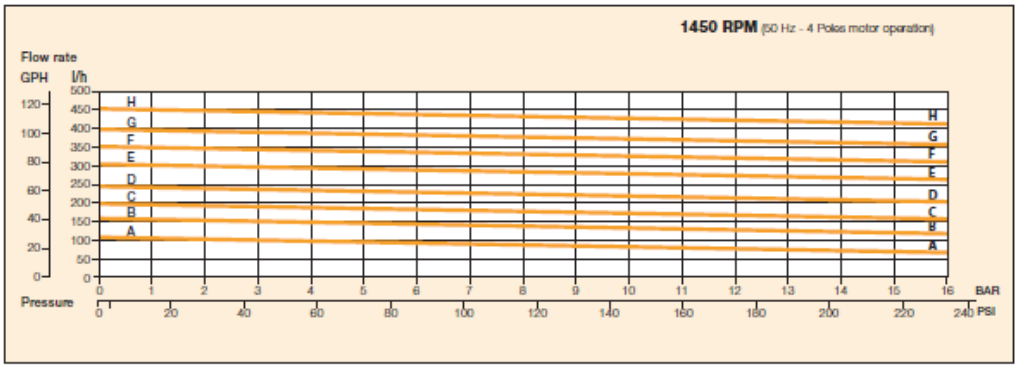


www.fluidotech.com

Brass rotary vane pumps PO 70-400 series

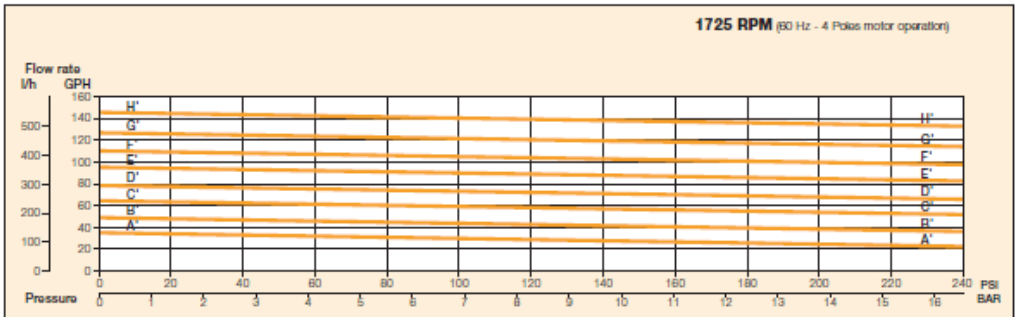
Model PO/PA/PW	070	071	074	071x	074x	100	101	104	101x	104x	1500	1501	1504	1501x	1504x	200	201	204	201x	204x
Figure			A-A					B-B					C-C					D-D		
Relief valve	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.
Strainer	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES

Model PO/PA/PW	2500	2501	2504	2501x	2504x	300	301	304	301x	304x	3500	3501	3504	3501x	3504x	400	401	404	401x	404x
Figure			E-E					F-F					G-G					H-H		
Relief valve	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.
Strainer	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES



Model PO/PA/PW	070	071	074	071x	074x	100	101	104	101x	104x	1500	1501	1504	1501x	1504x	200	201	204	201x	204x
Figure			A'-A'					B'-B'					C'-C'					D'-D'		
Relief valve	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.
Strainer	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES

Model PO/PA/PW	2500	2501	2504	2501x	2504x	300	301	304	301x	304x	3500	3501	3504	3501x	3504x	400	401	404	401x	404x
Figure			E'-E'					F'-F'					G'-G'					H'-H'		
Relief valve	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.	NO	STD	BAL.	STD	BAL.
Strainer	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES	NO	NO	NO	YES	YES



Note: Characteristics at constant motor speed, water at 20 °C (68 F) and bypass blocked.
For applications involving other fluids, high temperatures or unusual processing conditions, please consult the factory or an authorized Fluid-o-Tech distributor.

Fluid-o-Tech reserves the right to modify the above specifications and this publication at any time and without prior notice.

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WATERITE TECHNOLOGIES, INC.
PRODUCT SPECIFICATION SHEET
RO-MEM-001

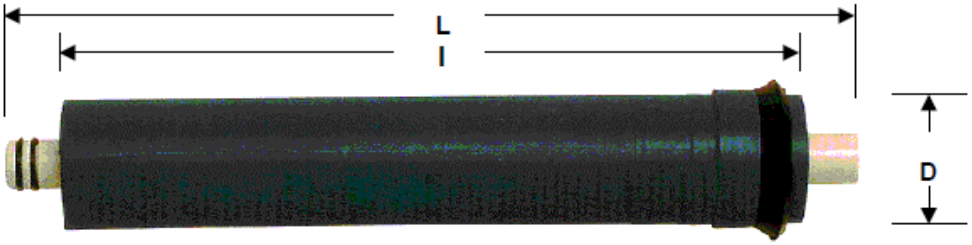
BLACK MAX RESIDENTIAL TFC REVERSE OSMOSIS MEMBRANE ELEMENTS

A. GENERAL SPECIFCATIONS

TYPE: Spiral wound TFC RO membranes, tape wrapped,
FEED WATER PRESSURE: 40 psi minimum, 125 psi maximum
FEED WATER TEMP: 45º C (113º F) maximum
FEED FLOW RATE: 2.0 gpm maximum
COLOUR: Black external tape with gray trim

DIMENSIONS:

Model No.	L		I		D	
	Inches	CM	Inches	CM	Inches	CM
BME1812R24	11.63	295	10.0	250	1.8	46
BME1812R36	11.63	295	10.0	250	1.8	46
BME1812R50	11.63	295	10.0	250	1.8	46
BME1812R75	11.63	295	10.0	250	1.8	46
BME1812R100	11.63	295	10.0	250	1.8	46



SPEC RO-MEM-001
May, 2002

PACKAGING: Elements are shipped in sealed bags and contain a preservative solution of 1-2% (by weight) of sodium metabisulphite (food grade).

TRADE NAME: ***BLACK MAX®***

B. PERFORMANCE SPECIFICATIONS

Model No.	Permeate Flow Rate		Minimum Salt Rejection (%)	Stabilized Salt Rejection (%)
	Gals/Day	Liters/Day		
BME1812R24	24	90	96	98
BME1812R36	36	136	96	98
BME1812R50	50	190	96	98
BME1812R75	75	285	96	98
BME1812R100	100	380	96	98

Production rate @ feed water of 500 TDS, 25ºC, system pressure @ 65 psi, 15 % recovery, pH 7-8. Permeate flow may vary +- 15%.

C. RECOMMENDED FEED WATER PRETREATMENT SPECIFICATIONS:

TDS: < 2000 TDS
HARDNESS: < 6 grains/gal. (103 mg/l)
TOTAL IRON: < .05 ppm
TANNIN: < .5 ppm
CHLORINE: < .1 ppm
pH: 5.5 – 9.5
ORGANIC/MICROBIOLOGICAL ACTIVITY: 0
MANGANESE: <.05 ppm
HYDROGEN SULPHIDE: 0
TURBIDITY: < 1NTU
SILT DENSITY INDEX: < 5.0

D. OPERATING AND STORAGE AND WARRANTY INFORMATION

1. Elements must be kept sealed and moist when in storage. Drying out will irreversibly damage the membranes.
2. Prevent elements from freezing, or being exposed to direct sunlight.
3. Elements are shipped in sealed bags and contain a preservative solution of 1-2% (by weight) of sodium metabisulphite (food grade).
4. Discard permeate from the first hour of operation.
5. Membrane Elements for residential systems have a one year warranty from the date of shipment. Warranty is void for membrane elements fouled by suspended solids, precipitates or biological growth. Membrane warranty is also void if the membrane elements are improperly used, poorly maintained or improperly stored.

Waterite

SPEC RO-MEM-001
May, 2002

2

Appendix E Supervisor Meeting Minutes

Friday, September 14th , 2012

The team met with Dr. Ugursal for the second time, and he confirmed that he would supervise the team. The project ideas that were originally proposed where the safer car seat design and the human powered water purification system. After this meeting, the team decided to focus on the human powered water filtration system instead of the safer car seat design. The car seat design was considered too expensive to test without sponsorship, and possibly beyond the scope of the design project.

Friday, September21st

The first tentative group design requirements were proposed. This included that the design should:

- Cost effective
- Durable
- Human powered
- Capable of providing water for a family of five
- Should be easy to ship and assemble if manufactured

The group also stated that 1st official deliverable was due within a week and a half, and were well underway, though still not focussed on what type of water the design should be capable of dealing with.

Friday, September 28th, 2012

The team presented the design selection memo to Dr. Ugursal. The focus at this stage of the project was a system for treating fresh water, and the different ways to do it. Some basic things that were considered when selecting a system were as followed;

- Cost analysis (is the design practical and cost efficient)

- Is it mass produced or produced on site

It was suggested by Dr. Ugursal that if the system was too be deployed in impoverished nations, it should be possible to build it on site with basic materials available to the local people. Also, if parts that were not available on site where needed, they should not cost more than 200 dollars.

Friday, October 5th, 2012

During this meeting, some more ideas were discussed briefly. On presented by Dr. Ugursal was that the design be extrapolated to harness animal power instead of human power if the system was to be scaled up. It was also discussed that it is possible to make certain components using simple materials, such as a pressure vessel by burying a plastic container. It was also made clear that all research and ideas pertaining to the project were to be recorded and dated in the project logbooks. This way a complete story of how the design progressed was.

The following meeting was rescheduled for Monday, October 22nd because of a scheduling conflict.

Friday, October 12th, 2012

During this meeting, the team presented Dr. Ugursal with some of the research for components and processes that could be employed at a minimal cost. These are listed below.

- Ceramic filtration
- Mechanical hand pumps for producing moderate water pressures
- Solar UV (ultra-violet) disinfection via plastic bottle.
- Bio-sand (slow sand) filtration

While a basic knowledge of these processes were attained, it was decided that to properly select a design, each major type of water filtration had to be researched before one specific filtration could be selected. Dr. Ugursal also recommended that the team speak to Dr. Graham Gagnon from civil engineering because he is considered an expert on water filtration. It was also decided that the

design selected would have to be site specific, because there was not one single design that was the most practical in all different situations.

Monday, October 22nd, 2012

In this meeting, all of the water purification research by each group member was shared. The types of filtration methods that were researched were listed below along with a brief description of their effectiveness.

Ceramics:

- Effective at reducing bacteria count
- Not effective against water born viruses
- Hairline cracks tend to form if over pressurized, compromising the filters effectiveness

Solar Disinfection:

- Kills up to 98% of pathogenic bacteria
- Only effective with full sunlight and type one plastic containers

Vacuum Distillation/Boiling

- Effective for removing dissolved salts and larger particles
- Inconclusive evidence that vacuum pressure has any effect on bacteria/viruses
- Inconclusive evidence that bacteria/viruses are separated from water during evaporation
- Too energy intensive to be viable for human power

Chlorine

- Residual disinfection properties, unlike UV sterilization
- Not instantly effective
- Chlorine has to be dispensed properly, failure to do so can cause illness

Activated Carbon

- Good for organic compound and chlorine removal
- Cannot be used for sterilization
- Carbon filters must be flushed before use
- Carbon filters permit bacterial growth

Slow-Sand Filtration

- Removes up to 99% coliform from influent water
- Found to remove certain viruses
- Sand must be prewashed in a controlled process before it can be layered in the filter
- Cannot filter highly turbid water

After discussing all of the above types of filtration that were researched, it was determined that slow sand filtration would be the best solution was applicable. However, it was found that no one method of filtration could handle highly turbid water. For the case where water is highly turbid, some sort of pre-filter/coagulation method would need to be employed for each filtration method considered.

Friday, October 26th, 2012

The possibility of designing a commercial filtration unit (one using commercially attained filters) alongside the slow sand filtration system was discussed. It was found that the best method to treat water was the slow-sand method. However the actual mechanical design component was somewhat limited without adding unnecessary complicated systems to the slow-sand filtration.

Wednesday, October 31st, 2012

It was determined that the use of a chemical post/pre-treatment would be too expensive for the situation being addressed, which is supplying water to impoverished people. It was also suggested by Dr. Gagnon that the design be site specific to best serve the needs requirements of the situation.

Friday, November 2nd, 2012

A site specific design was chosen utilizing the best method to address the sites requirements. A rural northern community's fresh water reservoir was contaminated by an influx of basin sea water. This phenomenon was described to be a rare event, however, without a local freshwater source, villagers were forced to travel over ten kilometers by snowmobile to haul water for daily use. Because the reservoir was a large still body, it was considered low turbidity, brackish water. For this site, it was calculated to be theoretically possible to meet the prescribed design requirements using a human powered reverse osmosis system.

Friday, November 9th, 2012

Dr. Ugursal explained why using bound, dated, page numbered logbooks are so important, as they may be used as evidence in a legal court case. Meeting was kept short, as there was a lot of system design work to do.

November, 16th, 2012

Team updated the supervisor with the design progress, demonstrating that the direction chosen was in fact feasible. The meeting was kept short because of the large amount of work yet to be completed.

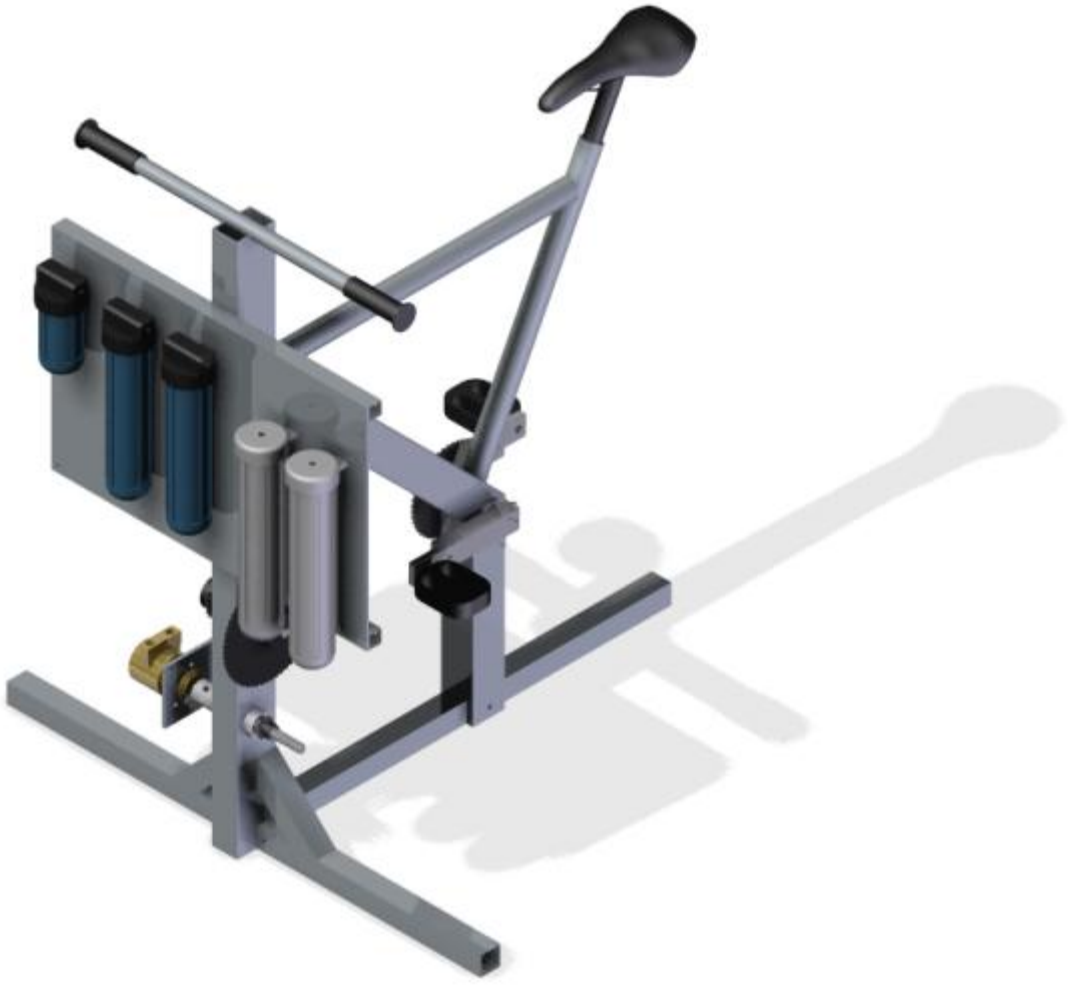
Friday, November 23rd, 2012

Team discussed the build report that was submitted earlier in the week. One suggestion made by Dr. Ugursal was to consider building the frame out of wood, to further simplify the design for on-site construction. Also, the team discussed a potential testing schedule for the winter semester, and seeking sponsorship from the membrane supplier to reduce the cost of the prototype. The following weeks design presentation was also discussed, suggesting that it should be well rehearsed and not last minute.

Appendix F Assembly/User Manual

Human Powered Water Purification System

Assembly/User Manual



System Assembly

Before beginning assembly, ensure to lay out the components required to assemble the system by checking with the following bill of materials. Before the assembly of the hydraulic system all male pipe threads should be wound thrice clockwise using Teflon tape with the thread-end facing the user. This will help speed assembly and ensure that all fittings seal properly when being threaded into place.

Part Name/Subgroup	Part Quantity
Fasteners	
Bolt – 3/8” X 3.5”	2
Washer – 3/8” STD	4
Washer – 3/8” Fender	4
Washer – 3/8” Locking	2
Nut – 3/8”	2
Bolt - 1/4” X 1”	5
Bolt - 1/4” X 1.5” UNC	4
Bolt – 1/4” X 1.5” UNF	2
Bolt – 1/4” X 2.5”	2
Bolt – 1/4” X 4.5”	2
Bolt – 1/4” X 5”	4
Washer – 1/4” STD	38
Washer – 1/4” Lock	19
Nut 1/4”	19
1.5” U-Bolt Kit*	2
2.5” U-Bolt Kit	4
6” Wire Ties	4
Frame Components	
Main post	1
Base cross piece	1
Main frame	1
Pump mount	1
Bicycle seat	1

Main Hydraulic Components	
3/8 OD Nylon hose	35”
P.S.V.	1
Carbon/Ultra housing filter kit	2
Sediment filter kit	1
R.O. membrane housing	2
100 GPD R.O. membrane	2
3/8’ Needle Valve	1
70 GPH Procon Pump	1
Check valve	3
Pressure Gauge	2
3/8 Comp. Tees	6
Nylon Pump Fittings	2
Suction Strainer	1
3/4" x 1/2" sch40 bushing	4
3/8" comp x 1/2" MPT brass fitting	4
1/8" NPTF Brass Comp. Fitting	6
1/4” Nylon Comp Fitting (Male)	1
1/4” Nylon Comp Fitting (Female)	1
1/2" NPTF Brass Comp. Fitting (Male)	1
1/2" NPTF Brass Comp. Fitting (Female)	1
3/8” Nylon Comp Fitting (Male)	1

3/8” Nylon Comp Fitting (Female)	1
Drive Train Components	
#35 – Roller chain	10’
#35 – Master link	2
#35 – 10 tooth sprocket (5/8” Bore)	1
#35 – 21 tooth sprocket (5/8” Bore)	1
#35 – 45 tooth sprocket (5/8” Bore)	1
#35 – 60 tooth sprocket (5/8” Bore)	1
Bearings (5/8” Bore)	6
3/16” Key stock	1’
5/8 Keyed Shaft**	3
Left/Right hand pedals	2
Left/right hand crank arm	2
Crank assist bar	2
5/8” to 7/16” lovejoy coupler	1

Frame Assembly

The frame assembly is designed to be assembled by one person alone. It consists of three main components, the main post, main frame and base cross-piece. These components are shown below (not to scale) in figure (38).

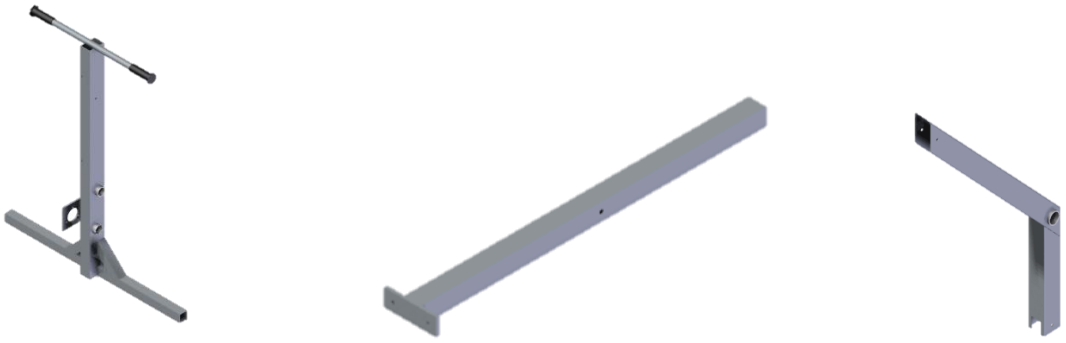


Figure 38 Left to right: Main Post, base cross-piece, main frame

Step 1: Begin by lining up holes in the base cross piece with the holes in the base of the main post. With one flat washer fit onto each bolt, slide each bolt through its hole. With bolts inserted fit another flat washer, followed by lock washer and nut to exposed threaded end of each bolt (Note: Every "bolted" connection hence forth shall be made using this method).

Step 2: Line up the two bolt holes in the main frame with those in the cross piece and main post. As shown below in figure (39). These connections are made using the two 3/8"× 3.5" bolts.

Figure 39 Main post and base cross-piece

Step 3: Next the seat is slid into the seat post, adjusted to rider height. The seat is then clamped in place using the two 1.5" U-bolt kit to force close the adjustment notch. Ensure one U-bolt clamp placed at the top of the adjustment notch, and one is approximately halfway down the notch. The frame should now look like figure (40) shown below (shown without fasteners).

Figure 40 Assembled frame

Drivetrain Assembly

Step 1: To assemble the drivetrain, firstly the six bearing must be pushed flush into their housings (two per housing) until the outside of the bearing is flush with the housing shown below in figure (41).

Step 2: Insert each shaft individually label crank, intermediate and pump into its respected housing shown below in figure (41).

Step 3: Fit the crank and crank assist arm and the 45 tooth sprocket to pedal crank shaft with keys as shown below in figure (41). Ensure that that the left and right crank shafts correspond to the riders left and right. With the crank arms fitted to the shaft, tighten the left and right pedals into their corresponding crank arms (Note that right is turned CW to tighten and left is turned CCW). After these components are aligned with proper clearance, the set screw in the sprocket and pinch bolts (1/4”×1.5” UNF) in the crank arms can be tightened to lock the assembly in place.

Figure 41 Shaft/bearing placement (left), Crank pedal assembly (right)

Step 4: Similar to step three, the 21 tooth sprocket is mounted on the intermediate shaft such that is will be driven by the 45 tooth sprocket on the crank pedal assembly, with the 60 tooth sprocket mounted to drive the ten tooth pump shaft sprocket as shown below in figure (40). Do not tighten the set screws to lock the gears to the keyway at this point.

Figure 42 Full drivetrain (shown without chain)

Step 5: With the sprockets installed, the two drive chains can be installed. The master links that connect the two ends of the chain require the spring clip be inserted into the groves on the master link with a flat head type screw driver.

Step 6: Align all chain/sprockets such the chain runs smoothly when the pedals are rotated slowly. With chain and sprockets aligned, tighten all of the set screws.

Step 7: Install the lovejoy coupler to both pump shafts and bolt the pump to the pump mount using the three 1/4”X1” bolts. Note that the set screw on the pump side of the coupler MUST be tightened on the flat surface of the shaft else the shaft may become damaged upon operation.

Step 8: RECHECK all bolted connections to ensure everything is tight (without deforming material) and will not loosen because of drivetrain vibration. With everything tightened the hydraulic system is now ready to be installed.

WARNING: Do NOT run pump at this stage. Dry running the pump at high speed will cause damage.

Hydraulic Assembly

Before the assembly of the hydraulic system all male pipe threads should be wound thrice clockwise using Teflon tape with the thread-end facing the user. This will help speed assembly and ensure that all fittings seal properly when being threaded into place.

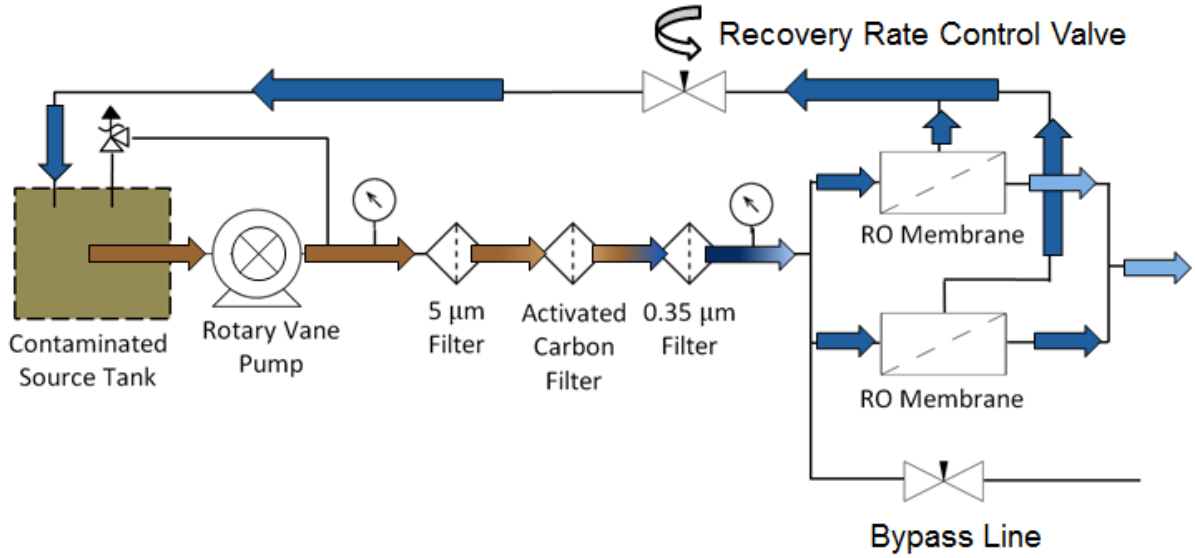


Figure 43 Hydraulic circuit

Step one: After taping all of the hydraulic fittings to ensure proper thread sealing, thread the two nylon 3/8 compression fittings into the Procon pump. Secondly measure two pieces of hose, one long enough to reach the source tank and connected to the **IN** side of the pump, and the other long enough to reach the pressure safety valve (PSV) that is mounted on the hydraulic circuit plate shown on the front of the bike connected to the **OUT** side of the pump as shown in figure (44) below. During this time the suction strainer and check valve can be attached to the suction line shown in figure (44).

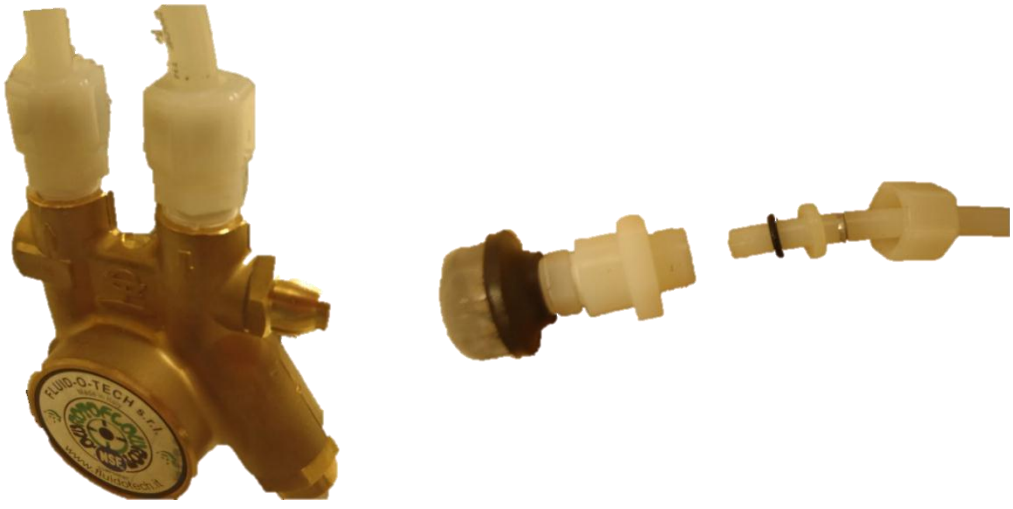


Figure 44 Procon pump connection (Down = IN, Up = OUT)

Step 2: With the pump installed, the filters brackets can be mounted as shown below in figure (45). At this step only mount the sediment filter to the bracket using the four self-tapping screws included in the kit. Note: It is easier to thread all fittings (without tightening the compression fittings) and adapters as shown before mounting the filters to the hydraulic plate. Then one by one mount the carbon and ultra-filters and tighten the compression fittings.

Figure 45 Filter mount assembly (Left to right: Sediment, Carbon, Ultra)

Step 3: With the filters mounted the PSV and pressure gauge located between the sediment filter and pump can be installed. The pressure safety valve not shown is plumbed off a tee from the main line with its return line plumbed back to the source tank in case of system pressure relief. The approximate assembly is shown below in figure (46)

Figure 46 Pressure valve (not shown is the PSV)

WARNING: DO NOT UNDER ANY CIRCUMSTANCES SET PRESSURE SAFETY RELIEF VALVE HIGHER THAN RATED 125 PSI! CATASTROPHIC FAILURE MAY RESULT IN SERIOUS INJURY AND PREMATURE SYSTEM FAILURE!

Step 4: The last stage in the circuit is the reverse osmosis (RO) membranes/housings. Please refer to manufacturer literature regarding proper membrane handling and installation. The RO housings are bolted to the hydraulic panel via two 2.5" U-bolt as shown below in figure (47). The RO concentrate lines are located on the left of each housing, and the permeate lines are shown on the right in figure (47). Not shown are the tee's and check valves installed on these lines to ensure the system stays "flooded" when not in use.

WARNING: REFER TO MANUFACTUROR LITERATURE TO ENSURE CONCENTRATE PERMEATES LINES ARE AS DESCRIBED. FAILURE TO DO
SO COULD RESULT IN SERIOUS ILLNESS!

Figure 47 Left: Reverse osmosis membrane housings (not shown is 2nd RO pressure gauge attached to second tee). Right: Shown are RO concentrate lines (left and tied together) and permeate lines (right)

Step 5: Install needle valve (recovery valve) into RO concentrate line as shown in figure (48) below. Ensure concentrate line out of the recovery valve is long enough to return to an adequate drainage point.

Figure 48 System recovery valve

Initial System Priming/Flushing

The first time water is pumped though the system it is important to have the recovery valve set to its FULL OPEN setting (turned counter clockwise until dial hits stop). This ensures that pressurized air bubbles are not being forced across the R.O. membranes upon initial start-up that will result in premature membrane failure.

WARNING: FAILURE TO ENSURE RECOVERY VALVE IS SET TO ITS FULL OPEN SETTING WILL CAUSE PREMATURE MEMBRANE FAILURE!

It is recommended that water be run through the system for at least ten minutes to ensure all air is evacuated. Before this system can be used to produce safe drinking water it is **VERY** important to read the data attained with the individual filters regarding required system flush time. The time required to flush the system may vary depending on filter/membrane manufacture. Water filtered across the reverse osmosis filters during the flushing period MUST not be used for human consumption.

System Operation

To ensure the longevity of the system, the following set of steps MUST be followed during start-up shut-down procedures.

NOTE: WATER GREATER THAN 5000 PPM AND COLDER THAN 20 DEGREES CELCIOUS WILL RESULT IN POOR SYSTEM PERFORMANCE AND LOWER THAT DESIRED FILTRATION RATES.

Step 1: Ensure recovery valve is set to open position.

Step 2: Ensure strainer and pressure relief lines are located in source water container, with the concentrate line being drained, and permeate line being collected as drinking water. Build pedal speed slowly to between 90-110 RPM (90 RPM = 1.5 revolutions of the pedal crank per second).

Step 3: Flood system with water for ten minutes or until air bubbles are no longer visible to the rider in the concentrate line. (If system has been flooded skip to step 4)

Step 4: Slowly RO pressure to 110 PSI by closing the recovery valve mounted on the handle bars and monitoring the 2nd pressure gauge (left of the rider). It is important to keep a constant pedal speed while this is done because system pressure depends on pedal speed.

Step 5: Continue pedalling until desired amount of permeate water has been collected. Reduce system pressure to 0 PSI and then stop pedalling.

The system is designed to

WARNING: FAILURE TO SUSTAIN MINUMUM PEDAL SPEED WILL RESULT IN PREMATURE PUMP FAILURE!

Appendix G CAD Drawings